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PROCEEDINGS

SEVENTH MEETING, SECOND HALF, 65TH SESSION

The Seventh meeting of the second half of the 65th Session of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, March 6th, 1930, when papers by Major F. M. Green, on "Resistance of Air-Cooled Engines," and by Mr. H. C. H. Townend, on "The Townend Ring," were read. In the Chair, the President of the Society (Colonel the Master of Sempill).

The PRESIDENT: The two papers to be read that evening were of extreme interest, and were prepared by two authorities who had studied the subjects for a considerable time. Major Green, who was holding an important technical position in the Armstrong-Siddeley organisation, had lectured to the Society on various occasions and required no introduction to such an audience. His last lecture to the Society, delivered in 1923, was entitled "Air Travel, with Special Reference to Helicopters," and he had also delivered lectures on "The Technical History of the Aeroplane," and "The Development of the Fighting Aeroplane." Mr. Townend, who had recently joined the Society, appeared on this occasion for the first time as the author of a paper. He was engaged as an assistant in the Aerodynamics Department of the National Physical Laboratory, and had done very valuable work which had led to an increase in performance of machines fitted with air-cooled engines.

THE RESISTANCE OF AIR-COOLED ENGINES

BY

MAJOR F. M. GREEN, O.B.E., M.INST.C.E., F.R.AE.S.

An internal combustion engine divides the heat energy obtained from its fuel into three fairly equal parts. About one-third of the energy becomes useful work; rather more than one-third escapes into the atmosphere in the exhaust gases: and rather less than one-third gives its heat to the cylinders and pistons. As its name implies, an air-cooled engine is one in which the cylinders are cooled directly by air. While the engine can and does part with a small amount of its heat by radiation, the bulk of the heat is carried away by air moving more or less rapidly over the surface of the cylinders and cylinder head, which are provided with fins in order to increase the surface in contact with the air. As the loss of heat is nearly proportional to the velocity of the cooling air the faster the aeroplane goes the better will a given engine be cooled; consequently, on a high-speed aeroplane it would be permissible to reduce the area of the cylinders in contact with the air; that is to say, we might save weight by reducing the size and number of fins or, alternatively, the velocity of air over

the cylinders need not be equal to the speed of the aeroplane. Air may be deflected from the engine by means of cowling, or by the shape of the body behind the engine or, more generally, by a combination of both.

My object in starting with the cooling of an air-cooled engine rather than with its drag is that these two factors are inseparably bound up with one another. If an air-cooled engine were concealed inside a body of streamline form then it would cease to be air-cooled. The drag that is added to a body by an air-cooled engine can conveniently be considered as a measure of the horse-power required for air-cooling. As aircraft increases in speed this loss of power becomes more and more important and the need for reducing it more and more urgent.

The number of heat units per horse-power that have to be transferred to the cooling air does not depend, except to a very slight extent, upon the arrangement of the cylinders. Whether these are radial, in line, or in Vee makes no real difference. For an engine working at a given horse-power its drag due to cooling will depend on the skill with which we arrange for the air to flow round the cylinder heads and barrels in such a way as to produce the minimum of turbulence while abstracting the heat units that must be dissipated to keep the engine at a reasonable temperature.

The first successful air-cooled aircraft engine was the 50 h.p. Gnome, which appeared in 1909. Aeroplanes at that time had a maximum forward speed of from 35 to 45 miles an hour, consequently the drag of the engine was not of much importance. The success of the Gnome engine was largely due to the fact that it did not depend for cooling to any extent on the forward speed of the aeroplane. The cylinders themselves revolved round the crankcase and thus provided their own cooling. When the Gnome and similar engines were used as tractors they were, in fact, fitted with cowling, but this was more to prevent the oil which escaped from the cylinders from blinding the pilot than to effect a saving of drag.

The next types of air-cooled engines which were used in large numbers were 8- and 12-cylinder Vee engines. The original 60 h.p. Renault had 8 cylinders arranged in two rows at right angles and the engine was supplied by the makers with a fan to cool the engine irrespective of forward speed. In the Maurice Farman aeroplane the engine was always fitted with a fan, and the cooling was satisfactory enough. When this type of engine was fitted into rather faster tractor aeroplanes, notably the BE 2/C, which had a top speed of about 90 miles an hour, it was found possible to do away with the fan and depend on the forward speed of the aeroplane to create a draught, which was increased by the slipstream of the airscrew. Air was taken into a space between the cylinders and escaped on either side between the two rows by passing round and between the cylinders and cylinder heads. A simple form of cowl was used on the 8-cylinder engines, the chief feature being that the space between the bottoms of the cylinders was blocked up and the air directed in a rather rough and ready manner so that it flowed with the highest velocity over the hottest parts of the engine.

When the 8-cylinder engine became obsolete through lack of power, the next step was to increase the number of cylinders to twelve. The actual methods of cooling were much the same, but for a tractor aeroplane it was found advisable to make the cowling higher so as to scoop in not only more air, but air which was moving at a higher velocity on account of the slipstream of the airscrew. The cowling was also sub-divided so that air could go direct to the rear cylinders. There is no doubt that this form of cowling added somewhat to the drag of the aeroplane, but there are no reliable figures available as to the increase of drag caused by the engine.

When Vee engines were cooled by their own fan, then the drag of the engine due to cooling would have been nothing if the body of the aircraft had been big enough to enclose the engine. The loss of power due to cooling would then be only the power taken to drive the fan, which was generally about 5 per cent. of the engine horse-power.

Rotary engines continued to be used in much the same way as they were originally. It is rather hard to ascertain how much horse-power was used in cooling these engines, because part of the horse-power was used directly in the windage of the rotating engine itself and part was due to the increase of body drag of the aeroplane. For various reasons rotary engines seem to be quite obsolete, so the question is hardly worth discussing.

Fixed radial air-cooled engines were developed at the same time as rotary engines, but originally met with little success. This was mostly due to poor cooling caused by the slow forward speed of the aeroplane at that time and also to lack of experience in cylinder construction. The speed of aeroplanes soon greatly increased and the construction of the cylinder heads was improved by using aluminium alloys of high conductivity and better shape. The result

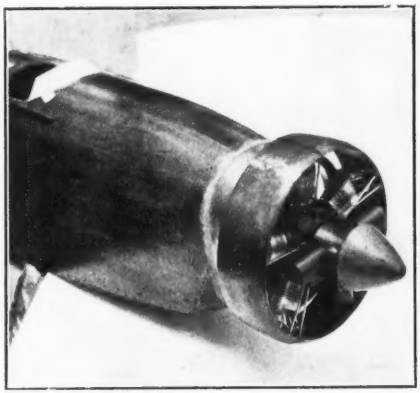
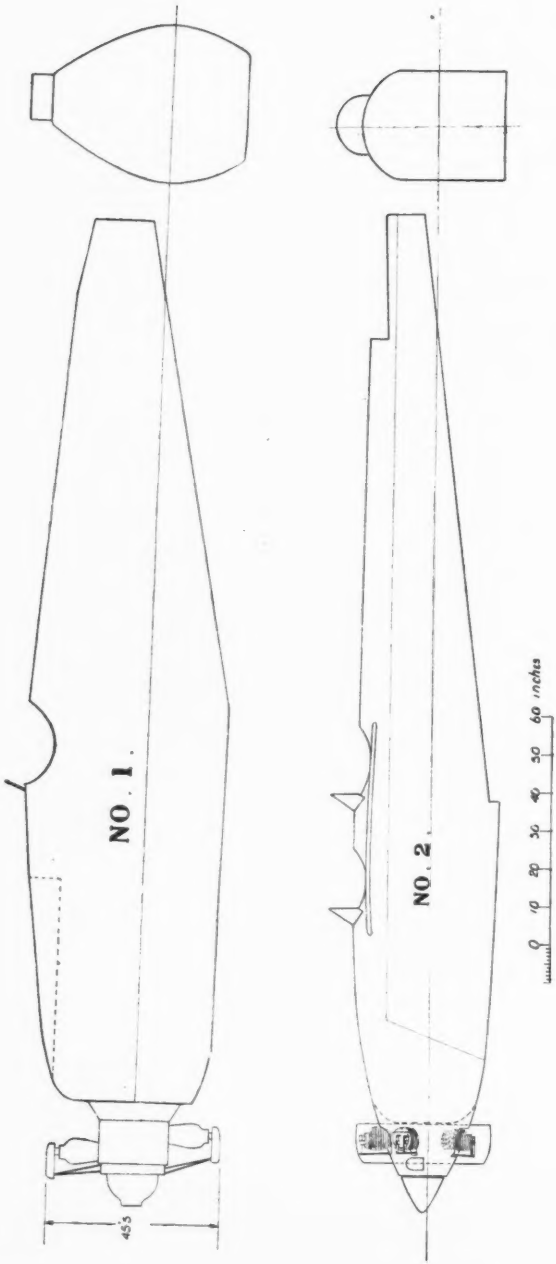


FIG. 1.

Wind tunnel model of Avian with Genet engine and Townend ring.

has been a revival in the use of fixed radial air-cooled engines and the purpose of this paper chiefly concerns the drag of this type of engine. I shall take as examples the Jaguar 14-cylinder engine which has a normal rated horse-power of 460 h.p., with a maximum of 500 h.p., and also the 5-cylinder Genet radial air-cooled engine of 80 h.p. My reason for choosing these two engines is that I am able to give both wind channel tests on models and full-scale tests on aeroplanes. As air-cooled engines are almost always used as tractors, I propose not to consider the question of their use otherwise.

Tractor aeroplanes may have either one or more engines. A single aircraft engine is generally fitted in front of the body, but in a multiple-engined aircraft the power units are frequently isolated. We will consider the question in two parts; firstly the drag of a radial engine in conjunction with a body carrying pilot and passengers, and secondly the drag of an isolated power unit. In describing model tests the figures given are the calculated values for full-scale at 100ft. a second. The tests were made on 1/5th and $\frac{1}{4}$th scale models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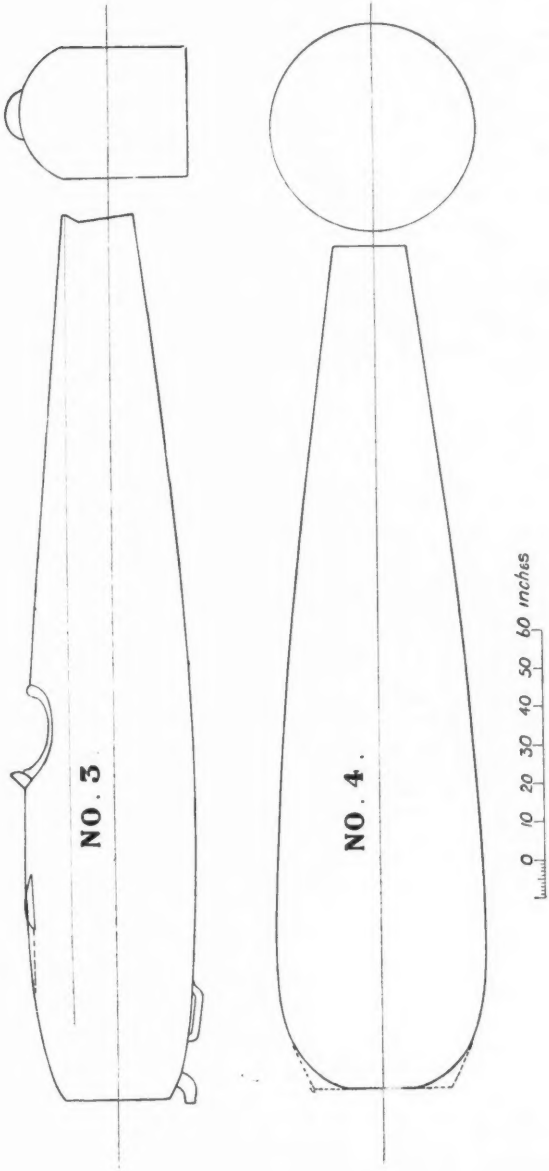


FIG. 2.

of considerable detail in the wind tunnel at Sir W. G. Armstrong Whitworth Aircraft Works. The tunnel is 5ft. by 4ft. and the wind speed was about 70ft. a second. The models were suspended by wires and the correction for these has been checked by repeating some of the tests with wires of different diameters. No attempt was made to test with an airscrew running, nor to measure engine cooling directly. Fortunately, measurements of drag on bodies that are not nearly perfect streamline shapes do not show much scale effect, and up to the present full-scale tests agree reasonably well with estimates based on model results.

The results of a number of tests are given in an appendix. You will see that the drag of a Jaguar engine by itself is between 70 and 80lbs. The drag of a typical two-seater aeroplane without windscreens is 20lbs. If the engine is placed in front of the body without any attempt at fairing, then the drag of the body plus engine is 55lbs. This was investigated at the R.A.E. some time during 1919, and a report was published suggesting various means of cowling so that the drag might be reduced without seriously affecting the cooling. The cowling suggested was very much like what is now known as the N.A.C.A. cowling, but as far as I know it was never tested in actual flight. The reasons were, firstly that no one knew how much cooling was really needed, and secondly, that it would have been difficult to make a satisfactory cowl and at the same time maintain reasonable accessibility of the engine. Actually an aeroplane was tested at the works of Armstrong Whitworth Aircraft, Ltd., with an enclosed cowling on somewhat different lines in 1925. This was done without wind channel tests and it differed considerably from the cowling suggested by the R.A.E. The results were that the speed of the aeroplane was increased by 4 to 5 miles an hour, which corresponded to a reduction of body drag of 30 per cent., but the increased weight complication and lack of accessibility made it obvious that the experiment was not a success. Referring again to the model tests it can be seen that adding a spinner to the airscrew reduced the drag from 56.4lbs. to 45.4lbs., while adding cowling to fair the space between the spinner and the engine made very little difference. These results were confirmed full-scale, when it was found that even for the purpose of the King's Cup race the cowl between the spinner and the engine was not worth fitting.

Coming now to later developments, you will see that fitting a ring round the engine, as described in Mr. Townend's paper, reduces the drag of the body plus engine to just over 30 lbs. The shape of the ring is fairly critical, but a number of different rings will give nearly equal results. The ring found to be most practical is a thin ring of aerofoil section and it has not been possible to make any other use of this except as a fairing. It has been suggested that the ring might be used as an exhaust collector, but so far I have not found any hope of using it in this way. When once you have found a reasonable shape of ring from wind channel tests the next step is to try it full scale. This was done on a Siskin aeroplane and the full-scale results showed that the increase of speed which might be expected from the wind channel results was actually obtained. I am not able to give you the details of the test, but the same aeroplane was tested thoroughly with and without a ring and the increase of speed varied from 5 per cent. to 3 per cent., according to height. Confirmation was obtained only from the results of speed tests. The effect of reduction of body drag on climb is also apparent, but as obviously the effect is much less important no attempt has been made to deduce the body drag from the rate of climb.

It will be seen that the increased drag due to adding an engine to a body of such a size that it will comfortably take two people and their equipment is to increase the drag from 20 lbs. to 30 lbs. at 100 ft. a second; that is to say, the power taken for cooling the engine at that speed is only 1.8 h.p.; 100 ft. a second is of course a low cruising speed, and taking 200 ft. a second (110 miles an

hour) as a more usual speed, then the horse-power wasted is increased by four times to 7.2 h.p. Again, an allowance must be made for the effect of the slip-stream and efficiency of the airscrew and this will bring the power taken for cooling the engine up to 9.6 h.p., which is 2.1 per cent. of the power of the engine. It is true that if the aeroplane is flying faster than 110 miles an hour the horse-power taken for cooling goes up nearly with the square of the speed, which really means that if you fly faster than this the engine will be cooled considerably more than is necessary. There is no inherent reason why cowling should not be developed, which would keep the horse-power required for cooling to a constant amount by reducing the air velocity over the engine, but this is a subject which is not yet fully investigated.

FIG. 3.

Model of aircraft with completely cowled Radial engine, tested at R.A.E. in 1917.

The size of the body in relation to the diameter of the engine is of considerable importance. The Jaguar engine needs a certain minimum cross-section of body in order to give the minimum drag. Fortunately this size is not very different from what has been found necessary for a single or two-seated military aeroplane. If the engine were fitted to an aeroplane designed solely for racing, then either the body would have to be bigger than necessary or else the Jaguar engine would have to be debited with rather more horse-power for cooling. For this reason I consider that a radial air-cooled engine is unsuitable for pure racing. Recent tests seem to show that the minimum body drag is obtained with a body a little bigger than used on the Siskin, Atlas and similar aeroplanes. The actual measured drag has been as low as 20½ lbs. with a body nearly circular in section with a Townend ring, and 55 inches in diameter. It must be remembered, however, that this low drag is probably obtained to some extent at the expense of the cooling of the engine and is only permissible on a fairly fast aircraft.

To sum up the present knowledge of the drag of the Jaguar engine of 460 normal horse-power, it is safe to accept the following figures:—

The combined drag at 100 ft. a second of a typical one or two-seater aircraft with engine, but without windscreens, is 30 to 33 lbs., of which 10 lbs. is the drag caused by cooling the engine. The minimum figure for any body fitted with a Jaguar engine yet tested is 20½ lbs., of which 10.5 lbs. is for engine cooling, but this result must be accepted with caution, as no full-scale tests have yet been made to prove whether the cooling is good enough.

An investigation of the Genet engine was made in much the same way and gave much the same kind of results. A model was made of the engine and of an Avian aeroplane and it was found that the engine increased the drag of the aeroplane at 100 ft. a second by only 3 lbs. when fitted with the most suitable form of cowling. This is very little, being in fact less than one-seventh the drag of the undercarriage and about the same as a good windscreen. This result was checked full scale on the Avian and the ring gave an increase of speed of about 4 per cent., namely, 3¾ miles an hour, which is near enough to the estimated figure. It must be remembered that while an increase of speed of 4 per cent. does not sound very much, it represents a decreased horse-power at the same speed of about 10 per cent.; that is to say, if you use a Townend ring or other suitable fairing you can carry 10 per cent. less fuel and work your engine at 10 per cent. less of its full power.

When the engine is not in front of a body then the loss of power that must be debited to cooling is the drag of the engine plus any fairing used behind it. In a tractor aeroplane this fairing is there anyhow in the form of the body that carries the crew, and for this reason the power wasted in cooling is mixed up with the power wasted in overcoming the drag of the engine itself.

The best figure yet obtained in the wind tunnel is 20½ lbs. for the engine and body complete. It is conceivable that we need not debit all of this to cooling, as if the engine is placed in front of a wing of thickness comparable to its diameter then we may save a portion of the profile drag of the wing itself. A recently issued N.A.C.A. technical note gives the drag of a 9-cylinder Whirlwind engine with N.A.C.A. cowling as 19 lbs. at 100 ft. a second when tested by itself. When in combination with a thick wing the added drag varied from just about one-half when the centre line of the engine is level with the nose of the aeroplane to many times more when it is put just below or just above the plane. The former position is probably not quite practicable, as there is no doubt that the reduced drag would be accompanied by a considerable drop in engine cooling.

To sum up, it is probably safe to expect the drag, due to cooling of a Jaguar engine used as an isolated power unit, to vary from 25 lbs. at 100 ft. a second on a slow aircraft to a possible 15 lbs. on a very fast aircraft, always assuming that the engine unit does not set up interference effects that are prejudicial.

One of the chief difficulties in deciding what form of cowling will be used is to know how much cooling is required for an engine in a particular aeroplane. This depends upon the speed of the aircraft, the greatest temperature at which it will have to work, the length of time that it will be flown on full throttle, and many other things. There is no absolute standard for the best working temperature of the engine. An engine may give trouble by over-heating, evidenced by pre-ignition, damaged valves and valve seats, burnt pistons, and so on. These troubles in practice seldom arise in a few flights, and it is rather unfortunate that it needs a great deal of flying to find out whether the engine is cooled well enough to ensure a long life between overhauls. All forms of cowling are likely to reduce the cooling of the engine to some extent. I think that Mr. Townend's ring reduces it very little indeed, and this is one of the reasons why it can be applied to an engine without elaborate full-scale testing. On the other hand,

it is fairly certain that many of the other forms of cowling, such as that used in experiments carried out by my firm in 1925, did reduce the cooling by an amount which was sufficiently large to be likely to cause trouble in the long run. Similarly, the drag of an aeroplane can frequently be reduced by not allowing a clear space behind the engine. This, of course, has an equally adverse effect on the cooling.

Finally, I want to mention what is probably one of the most important considerations of all in deciding what sort of cowling is the best to use, and that is simplicity. It is very surprising how difficult it is to make a cowling of reasonable weight which will not crack under the combined effect of air forces and engine vibration. When you add to this the necessity of getting at the engine for running adjustments you will have an idea of the difficulties of the problem.

FIG. 4.
Siskin aircraft with Jaguar engine and enclosed cowling made in 1925.

The ring I have described is, to my mind, far and away the simplest arrangement that is likely to work, and even this gave us a good deal of difficulty in finding a practical method of construction. The rings on which the first experiments were carried out were made of 22 gauge sheet steel and were in one piece. They were stiffened at the points of attachment and were bolted by means of brackets on to the cylinder heads. The rings have stood up to a good deal of flying without trouble, but in order to adjust the valves it is necessary to take off the ring, and this is hardly a quick enough job for practical purposes. A method of making the ring in seven sections is being developed which shows considerable promise. Up to the present the sections have been made of steel, but I hope that later on it may be possible to use a light alloy instead. The weight of the steel rings with attachment is about 30 lbs., but I think that eventually it will be possible to reduce this to a little more than half and still have a practical job which will stand up to hard wear and a certain amount of mishandling.

While a great advance has been made in the last year in reducing the drag of a radial air-cooled engine the work is far from being finished. With the

exception of the figures taken from the N.A.C.A. Note I have used only those of which I have more or less first-hand knowledge. The value of this paper will be enormously increased if members will add to it in the discussion by giving the results of tests on other engines, particularly those of shapes different from the radial engines with which this paper has been chiefly concerned.

No. 1 FUSELAGE.

Arrangement.	Drag lbs. at 100 ft. sec. full-scale.
(1) Fuselage, windscreen and cockpit	24.6 lbs.
(2) Ditto, with Mk. VI Jaguar engine	56.4 lbs.
(3) Ditto, with Mk. VI Jaguar engine and spinner ...	45.4 lbs.
(4) Ditto, with Mk. VI Jaguar engine, spinner and streamlined exhaust ring	42.5 lbs.
(5) Ditto, with Mk. VI Jaguar engine, spinner, streamlined exhaust ring and ring No. 1	30.8 lbs.
(6) As (5), but without spinner	31.9 lbs.

No. 2 FUSELAGE.

(1) Fuselage, both windscreens and cockpits	14.2 lbs.
(2) As (1), but with Genet engine and cowling (no magnetos)	23.4 lbs.
(3) As (2), but with magnetos	24.2 lbs.
(4) As (2), but with Townend ring	17.21 lbs.
(5) As (2), but with round exhaust ring	29.1 lbs.
(1) Fuselage, both windscreens, cockpits, nose of fuselage faired behind engine and spinner. Compares with (3) above	24.1 lbs.
(2) As (1), but no spinner	25.4 lbs.
(3) As (2), but with Townend ring	19.7 lbs.
(4) As (3) with streamlined exhaust ring	19.4 lbs.

No. 3 FUSELAGE.

(1) Fuselage, cockpits, oil radiator and windscreen ...	17.6 lbs.
(2) As (1), but with Mk. VI Jaguar engine	60.8 lbs.
(3) As (2), but with No. 1 Townend ring	36.35 lbs.
(4) As (2), but with No. 2 Townend ring	35.2 lbs.
(5) As (2), but with No. 3 Townend ring	32.8 lbs.
(6) As (2), but with No. 4 Townend ring	34.1 lbs.

No. 4 FUSELAGE.

(1) Fuselage, no cockpits, no windscreens	9.81 lbs.
(2) As (1), but with Mk. VI Jaguar engine	40.2 lbs.
(3) As (2), but with No. 1 Townend ring	22.25 lbs.
(4) As (2), but with No. 2 Townend ring	22.75 lbs.
(5) As (4), but with squarer corners behind engine	20.5 lbs.

THE TOWNEND RING

BY

H. C. H. TOWNEND, B.Sc., A.F.R.Ae.S.

Introduction

The work which forms the subject matter of this paper relates to a device for reducing the air resistance of an air-cooled radial engine. It can be added to the engine without completely enclosing the cylinders, either singly or collectively, in streamline casings of the conventional type, which usually render the engine inaccessible.

Origin

The ring, as used for this purpose, sprang in the first instance from an earlier wind tunnel experiment in no way connected with the problem of engine resistance, and it was only during the course of this experiment that the question of engine resistance emerged as a possible application of the results which would be of some practical importance.

Evolution

The experiment referred to was one in which it was desired to know, for reasons connected with research on body airscrew interference, whether there was any considerable interference between a large streamline ring and a streamline body when the two were disposed with regard to one another as shown in Fig. 1(*a*), the ring being supported independently of the body. The first ring to be tested was, as shown at (*a*), one having a thick section very roughly streamlined. It was found that the effect of this ring in the position shown was to *reduce* the drag of the body. Reversing the ring section (*i.e.*, placing its

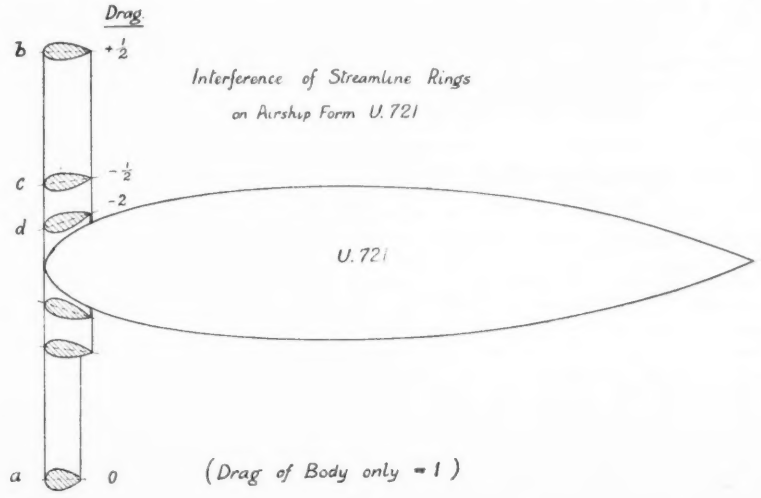


FIG. 1.

trailing edge foremost) showed a smaller effect; that is, the reduction in drag was not so great. The ring was therefore returned to its first position and the fairing considerably improved by smoothing it with plasticine. This produced a correspondingly greater reduction in drag; in fact, the drag became zero.

A ring of fairly good section (*b*) was then made, but gave a smaller reduction in drag, probably because its section was not so thick. When reversed this ring gave no reduction. After testing several other rings of various non-streamline sections, none of which gave reduction in drag, attention was concentrated on investigating the interference of streamline sections.

Interference of Struts

In order to facilitate these experiments some rough tests were made in which the ring was replaced by a straight strut of the same section as shown in Fig. 1(*b*). The advantage of this method of experiment lay in the ease with which it was possible to vary the distance of the section from the body, the section itself and its angle, all of which would have been very difficult to vary with rings. The results obtained were of the same character as with rings and suggested that the effect on drag would be best when the chord line of the ring section lay along the directions of the local streamlines. Working on these lines the rings shown at (*c*) and (*d*) Fig. 1 were tested, the angles being calculated from the formulæ for streamlines round an ellipsoid in a perfect fluid. Calling the drag of the body alone unity, its approximate drag in the presence of any ring is marked against that ring, in Fig. 1, the corresponding axial positions being nearly, though not quite, as shown. In the case of ring (*d*) the position of minimum drag (−2) occurred with the ring somewhat more forward than shown in the figure. In this latter case the range of position giving negative force on the body was extremely small; the body was strongly "towed" by the ring and equally strongly repelled from actual contact with it, being very stably locked aerodynamically in an intermediate position.

The force on the rings themselves was also measured and although the combined drag was very much higher than that of the body alone, it was frequently less than that of the ring alone and almost always less than the sum of the separate drags. Possibly this was to be expected for rings (*c*) and (*d*), Fig. 1, owing to the obliquity of the ring sections to the airstream in the absence of the body. In the case of (*b*), however, it was found that the drags of both ring and body were separately less than their free drags, suggesting a reduction in total turbulence, although the section of this ring was along the wind when the body was removed, and inclined about 3° to the local wind when the body was present.

Body with Excrescence Near the Nose

The next step was to examine whether similar reductions of drag would occur when the good shape of U.721 was spoilt by attaching to it an annular excrescence around the nose in the plane generally occupied by the engine of a tractor aeroplane. The changes in drag of the body thus modified, caused by a streamline ring, were very similar to those with the smooth body, though the actual drag was much higher, of course.

Bearing these last two results in mind, some practical example was then sought in which advantage might be taken of these interference effects. The first possibility that suggested itself was the case of a radial engine in the nose of an aeroplane body. So many machines were observed to be fitted with exhaust collectors of circular cross-section running round the body level with the cylinder heads that there seemed to be a chance here of killing two birds with one stone by providing an exhaust collector which should be a help instead of a hindrance by recovering some of the energy lost in engine drag instead of

throwing still more away on the normal exhaust pipe. In fact, it was even hoped that still a third bird might be killed with the same stone by utilising the large volume of the streamline exhaust collector as a silencer. Whether it is possible to accomplish all three results simultaneously it is still too early to say, and further full-scale tests now in progress must be awaited, but it may be said in anticipation that all three results have been obtained separately.

The first few tests on radial engines were so promising that the subsequent experiments were devoted entirely to them with the exception of a few other applications, to be described later, which were of more theoretical than practical interest at the time, chiefly in demonstrating the physical principle underlying the action of the ring when applied to a radial engine.

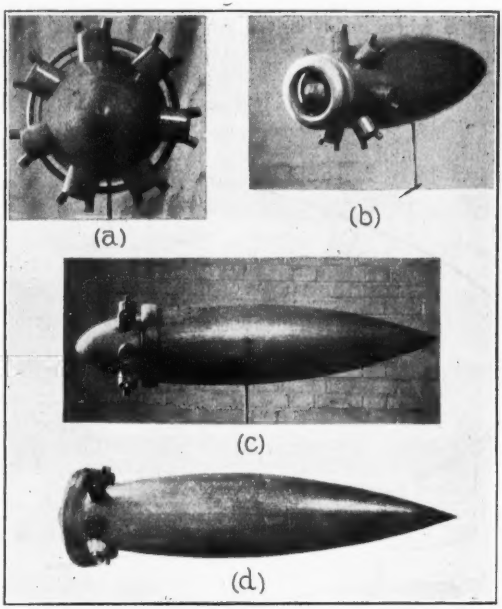


FIG. 2.

Some early rings tested on U.721 model.

Early Tests on Radial Engines

An initial attempt to discover the most suitable angle for the ring section relative to the body axis, under the new conditions of air flow introduced by the addition of the cylinders, was made by using four cylinders only, a pair on each side of the body. Opposite each pair of cylinders a short representative segment of a ring of symmetrical streamline section was attached to the body on pins, so that by bending the pins the angle could be varied over a small range. The ring segments were set to various angles and the overall drag observed and plotted against angle. It was found that there was a minimum appreciably lower than the drag of the engine and body alone.

At first, owing to faulty radial location of the section, the ring was found to be more favourable when placed behind the cylinders than in front. Subsequently, the front position, when properly selected, was found to be so much better that the majority of tests were confined to it. Fig. 2 shows some of the

early rings tested, of which (*d*) and (*b*) are the same as shown in Fig. 1 (*c*) and (*d*).

Physical Explanation of Ring's Action

Measurements of axial forces on ring and body separately showed that although the overall drag was down (25 per cent.) the apparent "drag" of the body and engine only was greatly increased. This was more than counterbalanced by the forward pull of the ring itself, which was large, and, of course, negative. It was clear that these forces were not drags properly so called, but the resultants of the true drag and forces due to the local pressure reaction between the ring and the body, which, in the case of the ring, made its drag appear negative. It was also evident that since the ring section was roughly along the streamlines when no cylinders were present, and since the cylinders

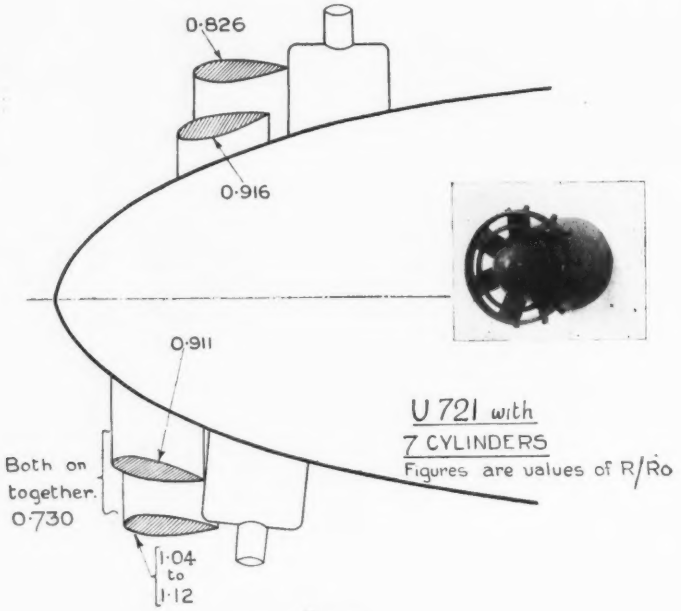


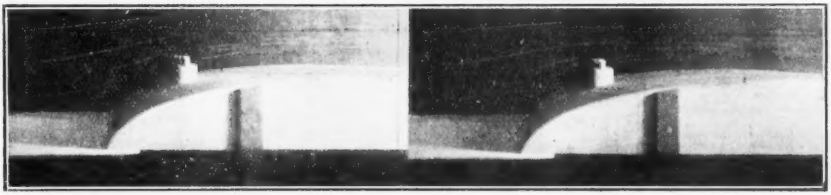
FIG. 3.

would certainly deflect the streamlines outwards, the ring section would in consequence be working at a considerable angle of incidence to the local airstream and therefore experiencing a lift outwards in such a way as to exert a downwash—"inwash" it has been more aptly called—towards the body surface behind the cylinders. From this it appeared that the ring would tend to make the streamlines conform as far as possible to their normal configuration without cylinders and thereby reduce the radial depth of the eddying wake caused by adding the cylinders.

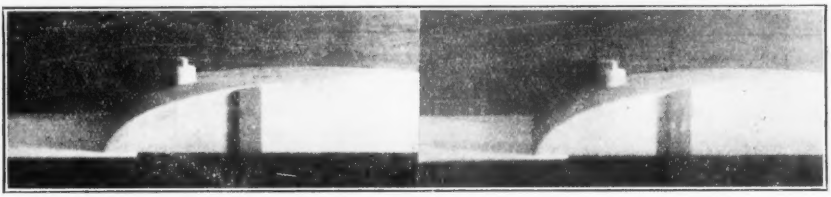
The next step, giving great support to this view, is illustrated in Fig. 3, which shows two streamline rings mounted concentrically in front of the engine. The upper and lower halves of the diagram show the engine in two different positions relative to the nose. The same rings were used in each position of the cylinders. With the cylinders in the rearmost position both rings separately

produced an appreciable reduction in drag. The smaller ring produced the same reduction in the forward position of the cylinders also, but the larger ring put the drag *up* from 4 per cent. to 12 per cent., the actual reading being very unsteady. Owing to the steeper slope of the nose of the body in the neighbourhood of the ring and the flatness of the angle of the larger ring it seems certain that the ring was installed with the cylinders in the forward position. When in this condition the smaller ring was also attached the increase in drag was converted into a 27 per cent. reduction ($R/R_0=0.73$). Since the smaller ring by itself only reduced the drag 9 per cent., it is evident that its presence inside the larger ring was sufficient to unstall it, thereby rendering it quite effective.

(a) In 7ft. wind tunnel.

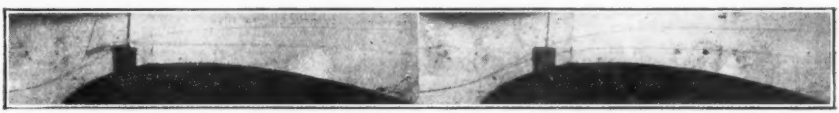


(1) *Flow without aerofoil.* (2) *With aerofoil at zero lift.*



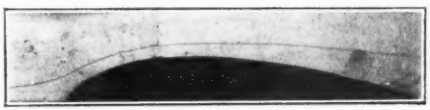
(3) *With aerofoil at moderately high lift (giving minimum drag).* (4) *With aerofoil above stall (drag increased).*

FIG. 4*a*.



(b) In 3in. water channel.

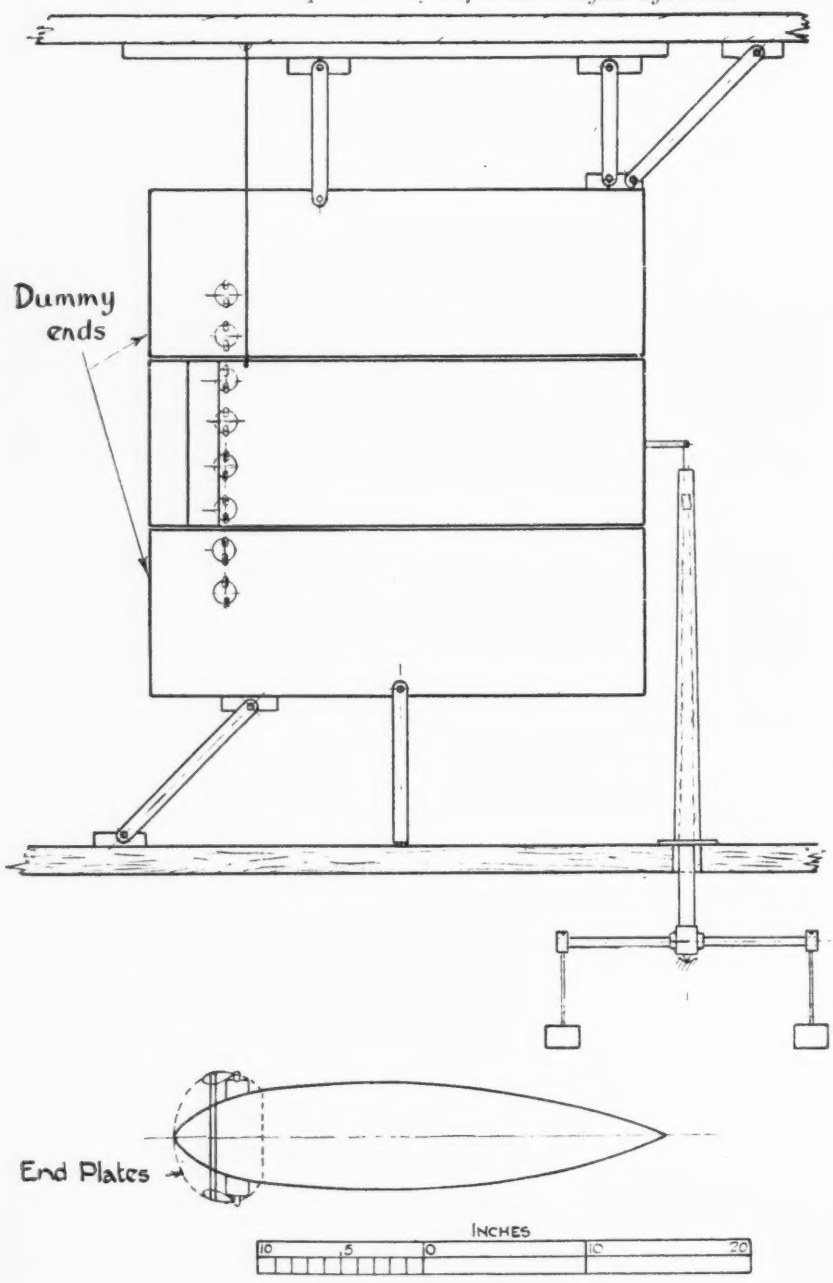
(1) *Flow with aerofoil (superimposed on flow with cylinders only).* (2) *Flow between cylinders (superimposed on flow past body only).*



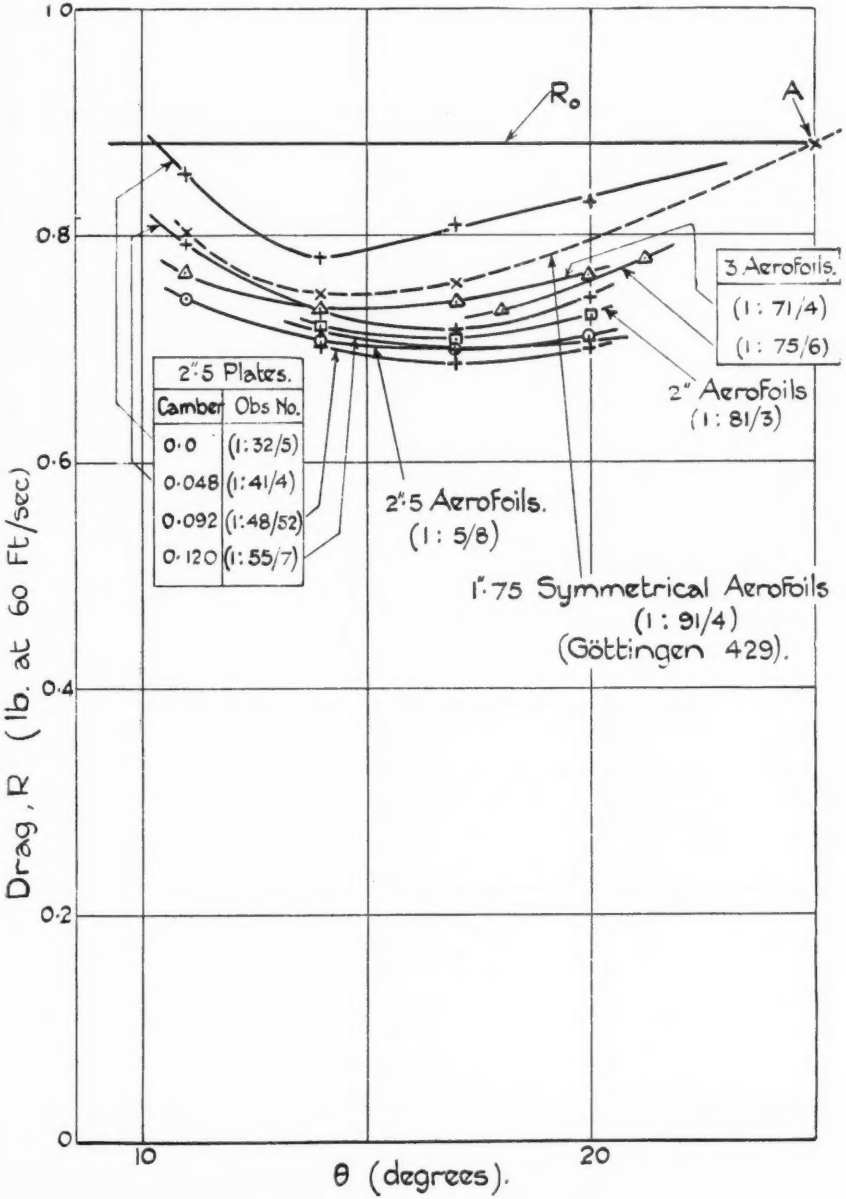
(3) *Flow round body only.*
Flow past two-dimensional models.

FIG. 4*b*.

Two-dimensional equivalent of U.721 with engine cylinders.



Two-dimensional equivalent of U.721 with engine cylinders.



Drag of model with dummy ends.

FIG. 5.

As a further check on these ideas some smoke experiments were made in which a jet of smoke was discharged just in front of the gap between two cylinders. Without a ring the smoke trail, after passing the narrowest part of the gap, was seen to be still diverging radially from the body surface to form a deep wake. With a ring in position the smoke trail clung very much more closely to the body. More recently this test has been repeated in a small (3in.) water channel with a two-dimensional model which will be described below, and also in a 7 ft. wind tunnel with streamers. Photos of these experiments are shown in Fig. 4 with and without the aerofoil representing the ring. The final justification of this explanation of the ring's action lies in its application to other cases of turbulence or interference, such as that produced by wing roots or sharp edges, as will be mentioned later.

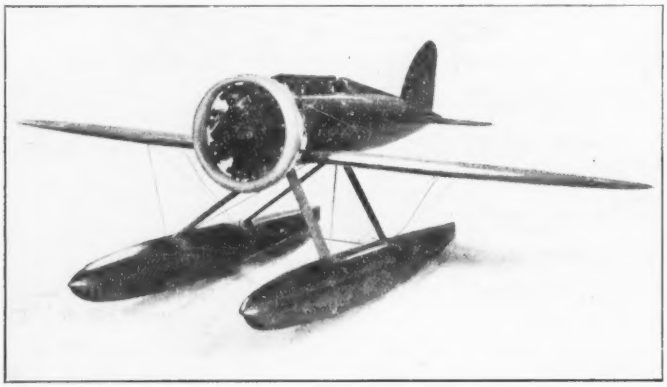


FIG. 6.
Short "Crusader" seaplane with ring "J" attached.

Having reached the conclusion that the important feature in a ring was that its section should be working at a fairly high lift coefficient it seemed probable that better results might be obtained if the section were chosen to have a good lift coefficient rather than a low drag coefficient. (When used in this connection the lift is of course radially outwards; no change in the net vertical force on the machine is implied.) At this stage, however, the effects of chord, radius and angle of section were also unknown quantities, very difficult to vary one at a time, especially with rings. It was therefore hoped that a short cut might be made by testing what was virtually, but not strictly, a two-dimensional analogue, shown in Fig. 5, in which the cylinders were the same as before, but the body was two-dimensional whilst the ring degenerated into a pair of straight aerofoils. With such a model all the variables could be varied with ease. This may appear a very crude and unlikely method of procedure, but as only *changes* in drag were required it was given a trial. Subsequently it was found that the results obtained, when applied to rings, were substantiated quite closely and gave a good idea of the relative importance of the different factors. Only in the value of the angle between the chord of the section and the axis was there a serious difference and this was due mainly to the difference in the streamline configuration of the flows in two and three dimensions. As the model was elliptical as far back as the maximum diameter the change in slope of the streamlines in going from two to three dimensions was calculated theoretically, and when this correction (of the order of 6°) was applied the agreement was quite reasonable. In any case the

effect of *variation* of angle was still applicable and it may be of interest, for the light it throws on the action of the ring, to refer to the dotted curve of Fig. 5 showing change of drag with change of angle. The aerofoils to which this curve applies, were of symmetrical section and were first allowed to weather-cock about an axis near the leading edge into their no-lift positions. The drag in that condition is shown at A; *i.e.*, it was the same as R_0, the drag with no ring. As the angle was flattened (θ decreasing, but incidence increasing) the drag fell continuously for about 10° and then increased again. If the figure be turned upside down it will be seen that the dotted curve bears a striking resemblance to the lift curve of an aerofoil, the point A being the point of zero lift, suggesting again that the reduction in drag is due to the lift developed by the ring section.

Development

Having described the evolution of the ring, a few particulars will be given of tests made on larger models in which the engine details were more accurately represented. Sketches of all the models and rings tested are shown in Figs. 16 and 17.

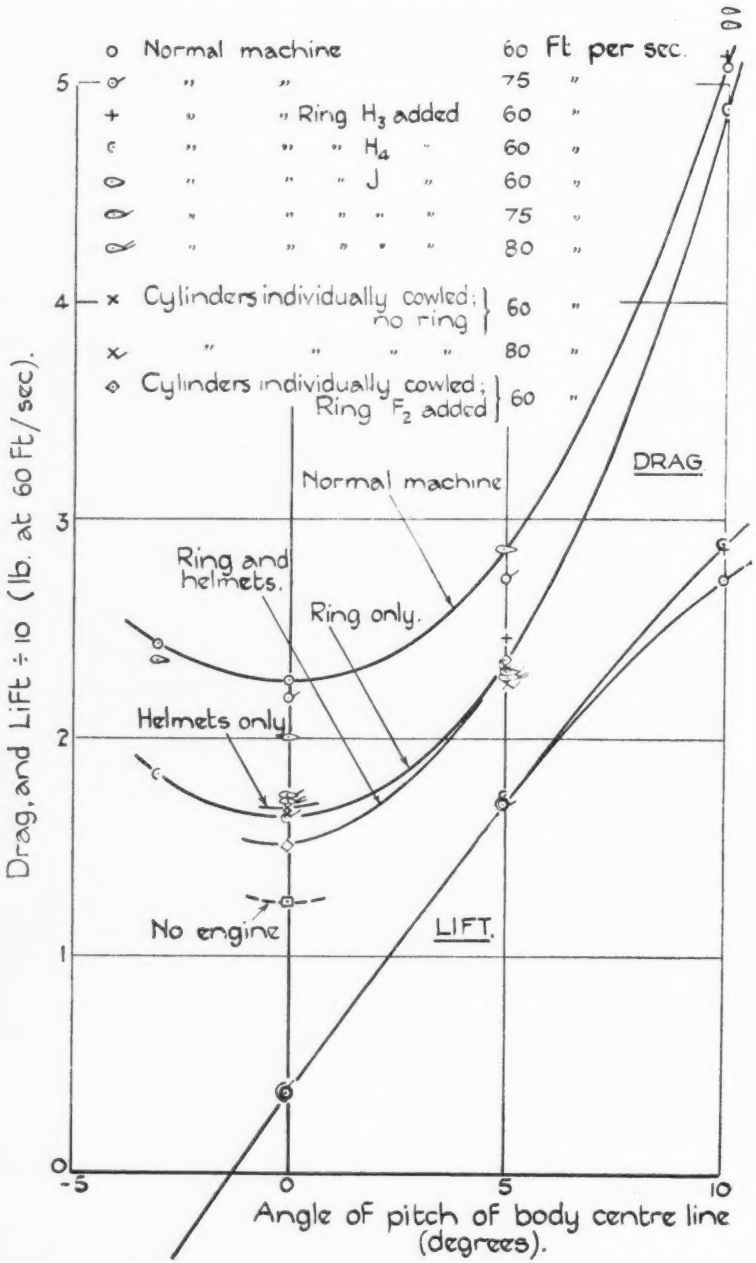
The first model on which such tests were made was that of the Short Crusader seaplane with Bristol Mercury engine (Fig. 6). This was the model, made to $\frac{1}{4}$ scale, which had been tested at the National Physical Laboratory in connection with the Schneider Trophy seaplane race and was kindly loaned by the Royal Aircraft Establishment for the ring tests. A check test was made on this model of the thick symmetrical ring already tested on the U721 model. A similar but somewhat more effective ring is shown in Fig. 6. On the body and engine only this gave a reduction of 34% in drag. With the complete model as shown the absolute reduction was slightly greater and corresponded to a percentage reduction on the whole machine of 20% (*i.e.*, $R/R_0=0.796$). A small range of incidence of the whole machine was also covered, and at 5° the L/D of the whole machine was increased from 6.2 to 7.6. The best ring tested at that stage gave $R/R_0=0.722$. Assuming the speed to vary as the cube root of the drag, the corresponding speed ratio would be $\sqrt[3]{1/0.722}=1.115$, an 11% increase. A little more than this would probably have been obtained with a different type of ring tested later.

With this model some individual cylinder helmets were available. They were dummies made in wood without any air flow through them. It was found that a ring attached in addition to these helmets reduced the drag still further. The ratio drag of body, helmets and ring/drag of body and helmets was 0.725 with a thick symmetrical ring. This result will be referred to again later.

The results on this complete model are shown in Fig. 7. The ring and helmets were not designed for simultaneous use and the result suggests that if a ring were applied first and side shields round individual cylinders fitted in afterwards good results might follow, and perhaps improved cooling.

Engines having Two Rows of Cylinders

Tests made with different numbers of cylinders from 3 to 9 showed that the percentage reduction in drag increased with the number of cylinders up to 9 cylinders. Tests on the two-dimensional model with two rows of cylinders indicated that good results should be obtained with this type of engine also. Messrs. Armstrong Whitworth Aircraft Limited very kindly lent a $\frac{1}{8}$th scale model of their Siskin aeroplane body with a 14-cylinder Jaguar engine attached, and several rings were tested on this model with good results. Fig. 8 shows the model fitted with valve rocker hats and spinner. A model of the ungeared engine without rocker hats was also tested. Fig. 9 shows rings fitted to this latter model. The best results were obtained with rings of cambered plate section, reductions of just over 50% being obtained ($R/R_0=0.49$). In comparing this with the other models it should be noticed that the basic shape of this body was not of such a good streamline form as the other models and was, in addition, fitted with


o Normal machine 60 Ft per sec.
" " " 75 "
+ " " Ring H_3 added 60 "
" " " " H_4 " 60 "
" " " " J " 60 "
" " " " " " 75 "
" " " " " " 80 "
× Cylinders individually cowled; no ring 60 "
" " " " " 80 "
◇ Cylinders individually cowled; Ring F_2 added 60 "
Normal machine
DRAG
Ring and helmets.
Ring only.
Helmets only
No engine
LIFT.
Drag, and Lift ÷ 10 (lb. at 60 Ft/sec).
Angle of pitch of body centre line (degrees).
0
1
2
3
4
5
-5
0
5
10

Quarter scale "Crusader"—complete model.
Lift and drag (uncorrected for tunnel wall effect) with various rings.

FIG. 7.

gun slots and windscreen. With similar bodies it seems that the results obtained with both types of engine would not be very different, notwithstanding the greater amount of obstruction with two rows of cylinders. Typical rings for this engine are shown *in situ* in Fig. 10.

FIG. 8.

Armstrong-Whitworth aircraft "Siskin," with "Jaguar" engine.

Full Scale Check Tests

In order to check the model tests in flight it was arranged that typical rings should be tested at the Royal Aircraft Establishment. The machine selected

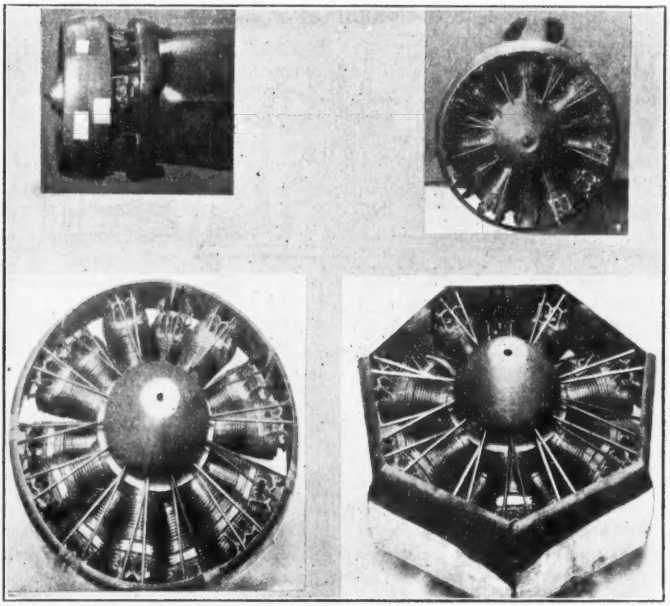


FIG. 9.

Rings as fitted to "Jaguar" engine.

for this purpose was the Bristol Bulldog Jupiter, and in order to obtain comparative results an approximate model of the body and engine of this machine on $\frac{1}{4}$ scale was made and tested at the National Physical Laboratory. The shape was modified slightly in that the body was a solid revolution, only identical

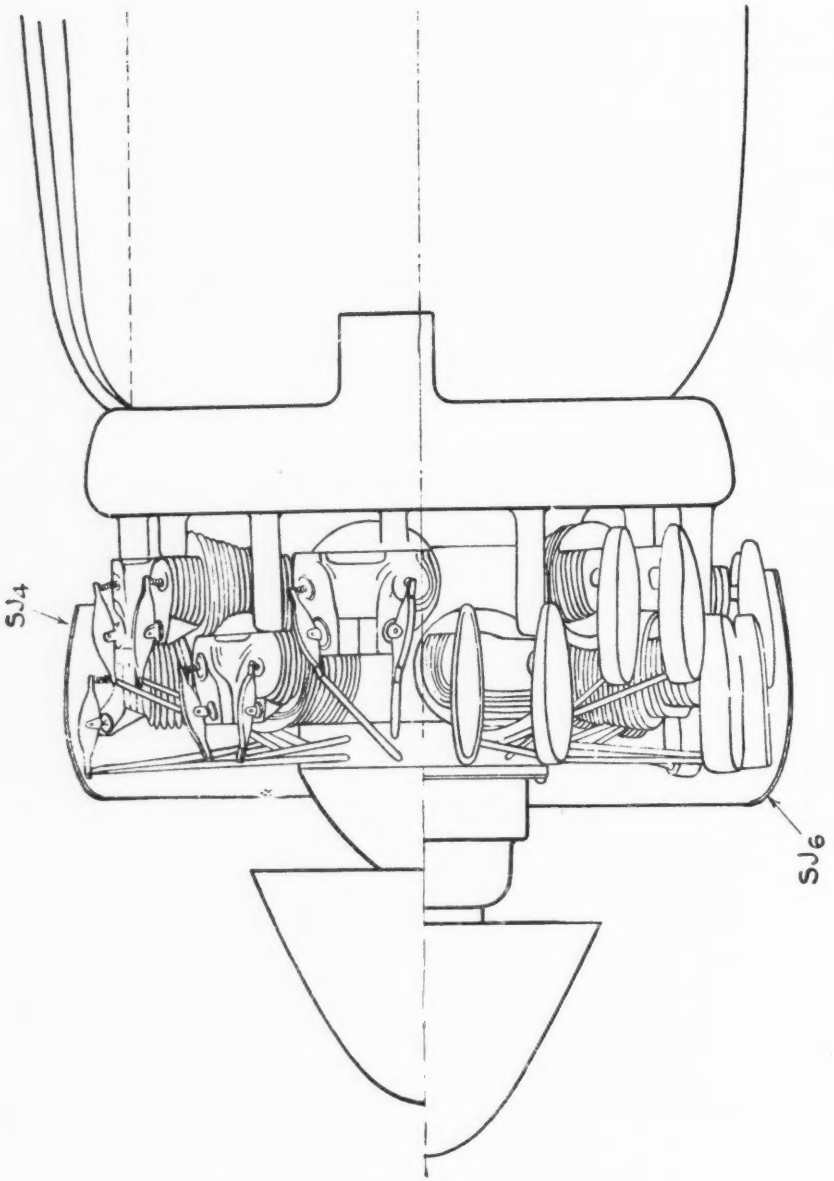


FIG. 10.

Details of nose of "Siskin Jaguar" model, showing rings SJ4 and SJ6. (Approximately to scale.)

with the Bulldog up to a point just behind the engine. The cylinders were those of the Mercury engine model with Jupiter type valve hats, and the diameter was adjusted to represent the Jupiter.

Airscrew Tests

An airscrew was fitted to this model and the effect of the ring on the overall performance was measured over the full range of V/nD. In addition some measurements were made with a small Pitot tube of the velocity between the cylinders. Additional rings were also tested and with a ring of cambered plate section having a chord of 16in. (full scale) a drop in drag of 60 per cent. was obtained ($R/R_0=0.40$). A photo of this is shown in Fig. 11. The fact that this ring was a polygon, if one may say so, makes very little difference, though the circular shape is probably slightly superior. The efficacy of this ring, as measured by the change in overall thrust of the combination, was maintained over the whole working range of V/nD, the body being at zero pitch. The overall maximum efficiency was raised from 61 per cent. to 68 per cent. Complete removal of the engine gave a maximum efficiency of 72 per cent., *i.e.*, adding the engine to the body produced an 11 per cent. drop in maximum efficiency; adding the engine and ring, only a drop of 4 per cent.

Thick Symmetrical Section

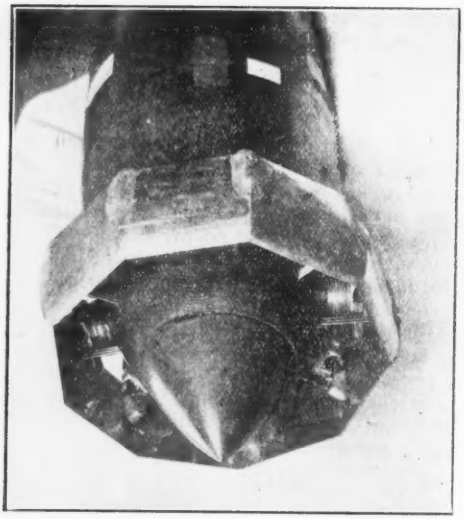
Fig. 12 shows a ring of thick symmetrical section on the Bulldog model. This type of ring section is fairly sensitive to its precise situation in relation to the engine cylinders, etc. Anything which tends to stall the section should be avoided and for this reason the outer surface should be kept smooth and projecting valve covers should be faired into the ring with fillets. The plasticene fillets shown in the photo have quite a marked effect; they are fairly important for most other ring sections also. An illustration of the sensitiveness of this section is shown in Fig. 13, which shows the scale effect on the drag of the model when fitted with this ring. The sudden increase in drag below 60 ft./sec. is presumably due to the stalling of the section which then increases the body drag very considerably, although when unstalled the ring is fairly effective, giving $R/R_0=0.52$. Incidentally this value of R/R_0 is considerably better than that obtained on the Crusader model body with the same ring, which gave $R/R_0=0.66$. The position of this ring relative to the cylinder heads is favourable to its use as an exhaust collector and silencer if the somewhat formidable mechanical difficulties of fixing it in such a position can be overcome. It should be mentioned that another symmetrical ring of little more than half the camber, but otherwise the same, proved to be comparatively poor for reducing drag. The ratio of maximum thickness to chord for the thick section was 0.394.

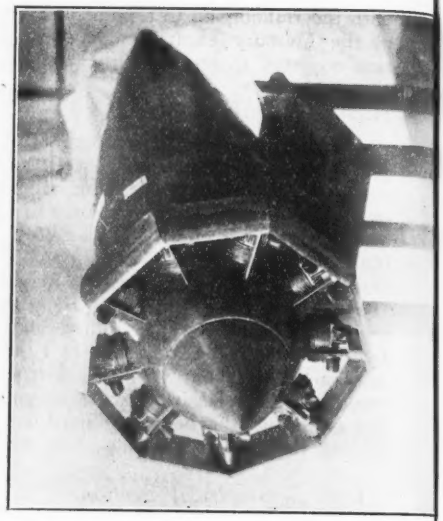
Some Main Results

The chief results will now be summarised with regard to the effects of varying the characteristics of the ring, *i.e.*, its section, chord, angle, etc. A systematic variation of these quantities was sometimes difficult to make without an excessive number of rings, except with the two-dimensional model, so that the results are not by any means exhaustive, but the following conclusions may be stated with some confidence:—

Section.—The thin cambered plate sections generally give the best reduction in drag. If, however, the ring is also required to collect the exhaust gases or silence the engine, it is quite possible aerodynamically to obtain a pretty good reduction with a *thick* symmetrical section.

Chord.—The reduction in drag increases steadily with increase of chord up to 12 in. or 14 in. (full scale) and then more slowly. The further improve-





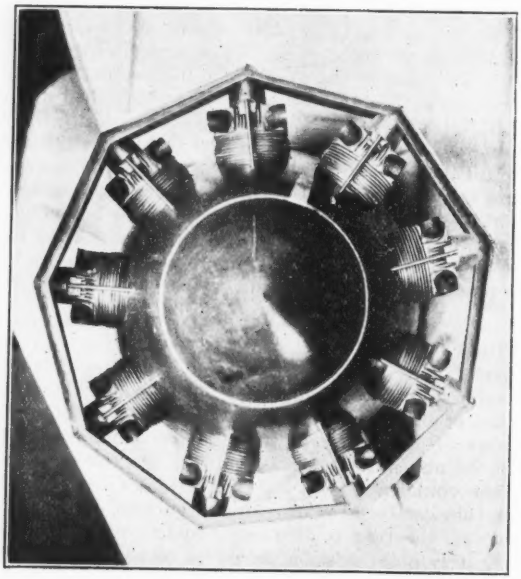


FIG. 11.
$R/R_0 = 0.40$.
Ring of cambered plate section on Bristol "Bull Dog" (modified).

ment in going to 16 in. is slight—of the order of 2 per cent. or 3 per cent. of R_0. At the same time, in these tests the chord was not increased to the point where it was actually a disadvantage, except in one solitary case in two dimensions, in which a chord corresponding to about 18 in. (full scale) was tested

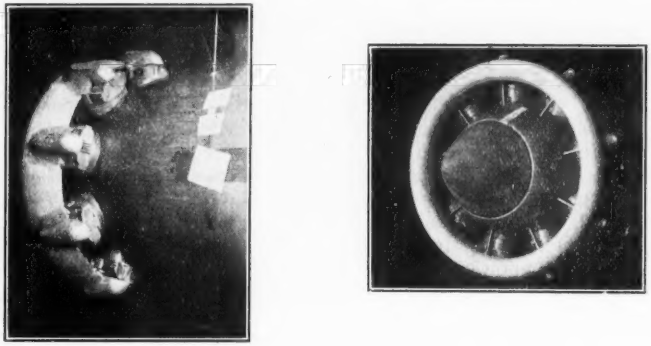


FIG. 12.

Ring of thick symmetrical section on Bristol "Bull Dog" (modified).
$R/R_0 = 0.52$.

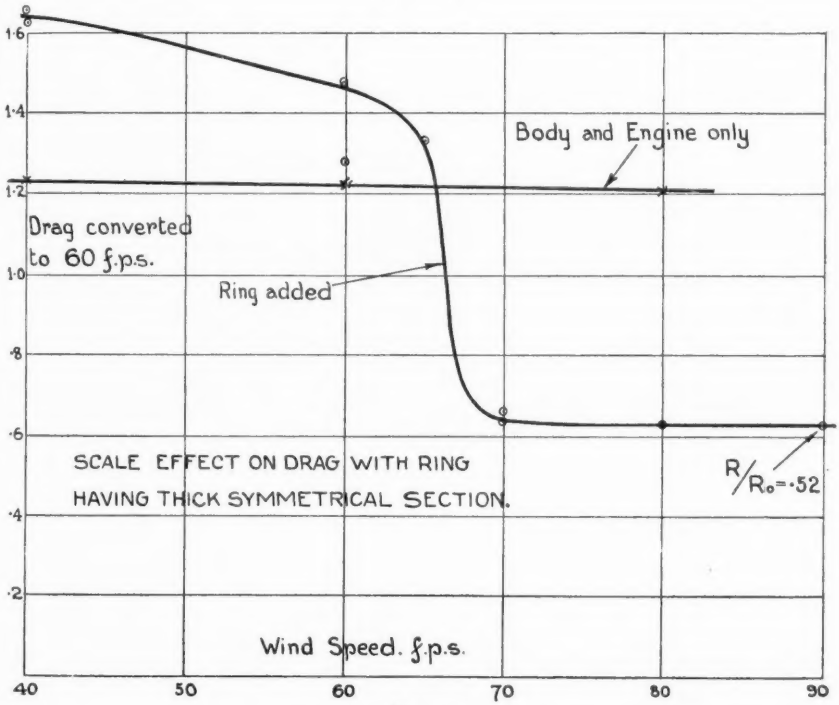


FIG. 13.

and appeared to be too great. It cannot, therefore, be considered proved that a larger chord would always be detrimental, although it may be presumed that from most practical points of view the smaller the chord the better.

Camber.—In the case of the cambered plate sections the best results were obtained with a camber of 0.09 to 0.10 chord. With symmetrical sections the really thick ones appear to be better than the moderately thick, possibly through greater shielding of the valve rockers. The flow between the cylinders is also good with these sections.

Angle.—It is not possible to give a definite value for the best angle of the chord line or the no-lift line to the body axis, as it will depend to some extent on the shape of the nose. It should, however, be fairly flat, that is, at such an angle to the *local* wind stream that the section shall be working at a fairly high lift, though not high enough to risk stalling. In most cases the no-lift line of the section should be inclined at 3° or 4° to the body axis, such that, if produced, it would intersect that axis in front of the nose. Turning the leading edge of the ring too much inwards in an attempt to give the nose a more conventional entry is generally detrimental. For instance, it is not satisfactory to place a large cowl over the whole engine and cut its front and rear edges back successively until only a "ring" is left, as the chord of the resulting ring will almost certainly make much too high an angle with the body axis, *i.e.*, too low a lift, to give maximum reduction in drag. The variation of drag with angle was shown for two dimensions in Fig. 5.

Location of Ring.—For a ring having a chord 12 in. long, the plane of the trailing edge should be situated close to the centre line of the engine cylinders and with larger rings somewhat further over the cylinders. The radial situation should be such that the diameter of the trailing edge is not greater than that of the engine. It is probable that the best results will be obtained when the rear edge of the ring is cut away to fit round the valve rockers, but if this is done the rocker hats should be faired into the upper surface. It may be preferable to permit small projections if properly faired than to increase the size of the ring so as to surround everything. No exhaustive tests were made on radius.

These remarks are not intended to apply to the Jaguar type of engine, which must almost necessarily be entirely surrounded. Possibly a relatively bigger radius would be an advantage in that case.

Other Applications of the Ring Principle

If the explanation of the ring principle that has been given is correct, then it should be possible to devise other experiments in which reductions of drag would be expected to follow its application. Several such experiments were made and in all cases a reduction was obtained. Although some of them, if developed, might lead to useful applications, they are mentioned here mainly as illustrations of the effects that can be produced by this method.

It has already been mentioned that a ring was effective in reducing the drag of the "Crusader" model when already fitted with streamline helmets over individual cylinders. This suggested that the interference known to exist between such helmets when so close to each other as in a 9-cylinder engine was due to the air tending to break away rather than traverse the grooves formed between adjacent helmets, even though they were along the wind. From this it would follow that other examples of such grooves might be capable of similar treatment.

Wing Roots.—One obvious example of such a groove was that formed by the junction of a wing with the fuselage of an aeroplane, as in a low-wing monoplane. The interference between the wing and body is known to be greatest when in this relative position. Fig. 14 shows the application of the ring idea to this

case. A short strut of aerofoil section is shown bridging the groove, its angle being such as to induce the air to flow along the groove. The reduction in drag for the case illustrated at zero incidence of the wing was about two-thirds of the reduction obtained with the best filleting (shown dotted). The effect at higher incidences was not tested.

Body with blunt nose.—Another test was made in which a ring was applied to a body having its nose practically cut off short, the sharp edge being slightly rounded. A considerable improvement was obtained here also.

Bare 9-cylinder Radial Engine.—Even when a radial engine has no fairing in front or behind, its drag was reduced 25 per cent. by adding a ring.

Flat Disc.—The last named test suggested that even the drag of a flat disc could be reduced by this method. To test this a ring having a cambered plate

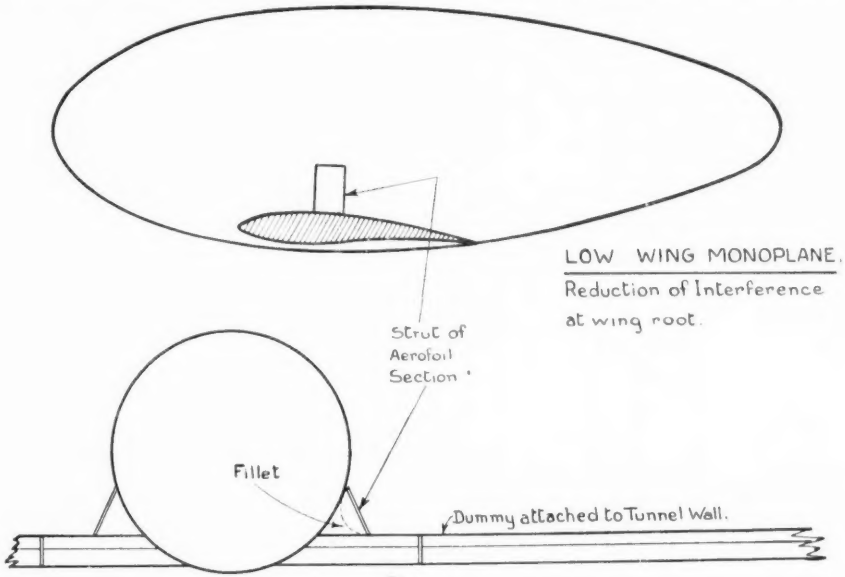


FIG. 14.

section was attached by three radial wires to each, in turn, of a series of discs of varying diameter. The position of the rings is shown in Fig. 15. This process was equivalent to testing one disc with a series of geometrically similar rings. The reductions obtained were very marked. When the ring diameter was about 1.5 times that of the disc the value of R/R_0 was 0.38, a 62 per cent. reduction. It is possible this result might have a bearing on the drag of such excrescences as windscreens.

It is perhaps significant that for rings whose diameters do not greatly exceed that of the disc, the chord of the ring makes only a trifling difference to the effect on the overall drag, whilst for larger ring diameters the effect of chord length is pronounced—increase of chord producing a marked decrease in drag. Some of this may, however, be due to a smaller angle (5° instead of 10°).

Conclusions

The general inference from all this is that where excrescences or interfering bodies give rise to considerable turbulence the resulting drag may often be

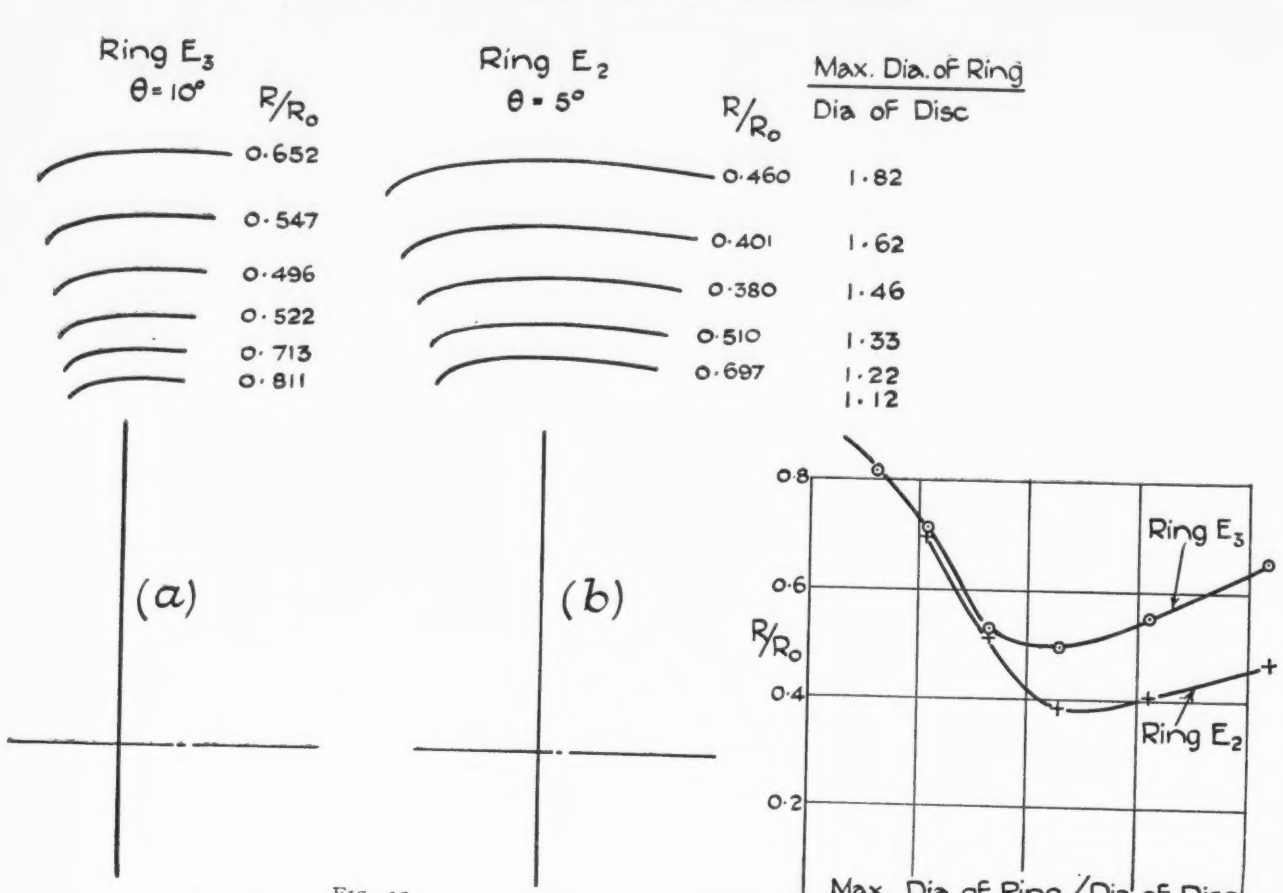


FIG. 15.
Effect of rings on drag of circular disc.

appreciably reduced by adding what is virtually a guide vane, judiciously disposed, and made of approximately aerofoil section so as to have good deflecting powers. By such means air which would otherwise go astray may be helped round corners without causing so much disturbance.

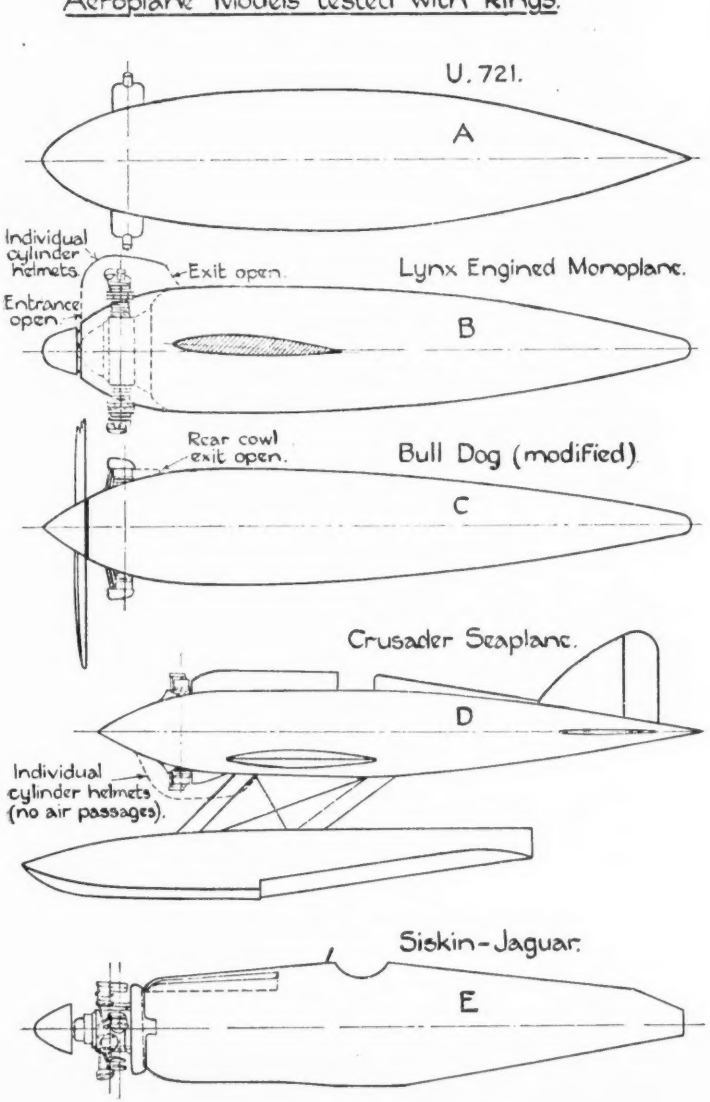


FIG. 16.

Max. Dia of Ring / Dia of Disc
1.2
1.0

FIG. 15.
Effect of rings on drag of circular disc.

Before concluding it may be as well to draw attention to one or two points of some practical importance.

In measuring forces on ring and body separately it was found that the axial force tending to pull the ring and engine apart was very considerable—of the

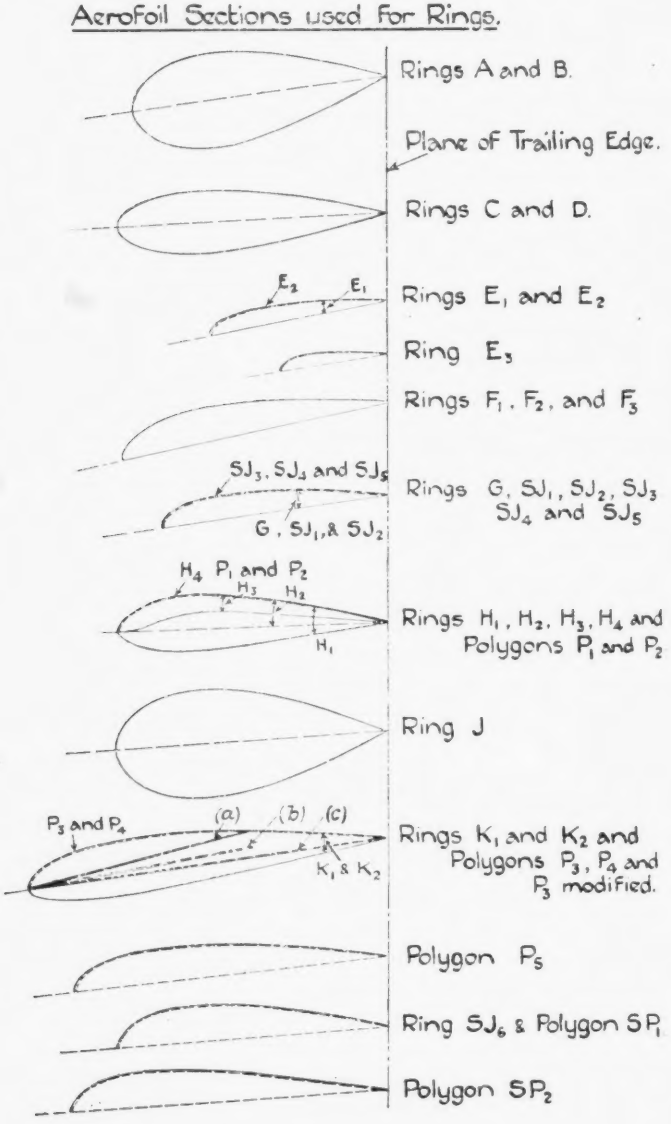


FIG. 17.

A SELECTION OF TYPICAL OBSERVATIO

Sketches of the models are shown in Fig. 16 and of the rings in Fig. 17. Dimen
is taken). θ=angle between chord and body axis; x=axial distance between centre
edge is in front of cen

Model.	Diam. (ins.) of Engine on Model.	Ring.	Chord.	Radius of Tr. Edge of Rings.	θ degrees	Axial Position x.	Speed of test: v. ft./sec.
*"Crusader," no wings, tail or floats (9 cylinders)	12		—	—	—	—	60
Ditto	—	A	0.2365	0.462	8	0.125	60
			—	—	—	0.0633	60
			—	—	—	0.0408	60
			—	—	—	0.0217	60
Ditto	—	J	0.250	0.483	4	0.131	80
			—	—	—	0.0817	80
			—	—	—	0.0308	80
			—	—	—	0.0308	60
			—	—	—	0.0308	60
Ditto	—	H_1	0.250	0.483	2	0.0358	80
		H_2	0.250	0.483	2	0.0358	80
		H_3	0.250	0.483	2	0.0358	80
		H_4	0.250	0.483	3.4	0.0358	60
Ditto, engine removed and cylinder holes papered	—		—	—	—	—	60
Ditto, cylinders cowled by individual dummy helmets	—		—	—	—	—	—
Ditto, ditto, ring in addition ...	—	A	0.2365	0.462	8	0.1775	75
			—	—	—	0.154	75
			—	—	—	0.105	75
"Bull Dog" (modified) (9 cylinders)	13.6		—	—	—	—	60
Ditto	—	J	0.221	0.427	4	0.0213	90
			—	—	—	—	80
			—	—	—	—	70
			—	—	—	—	65
			—	—	—	—	60
			—	—	—	—	40
Ditto	—	F_3	0.221	0.431	8	0.0390	60
			—	—	—	0.0132	60
N.B.	—		—	—	—	−0.0103	60
			—	—	—	−0.0140	60
Ditto	—	H_4	0.221	0.427	3.4	−0.0221	60
Ditto	—	K_1	0.294	0.482	8	−0.0478	60
		K_2	0.294	0.482	3	−0.0478	60
Ditto, polygonal ring	—	P_1	0.221	0.490	8.5	−0.00956	60
Ditto, ditto	—	P_1	0.221	0.490	8.5	−0.00956	60
Ditto, ditto	—	P_3	0.294	0.482	8.4	−0.0456	60
		P_3	0.294	0.482	8.4	−0.0478	60
		This was the best result obtained w					
Ditto, ring modified as (*a*) Fig. 17	—	P_3	0.294	0.482	8.4	−0.0478	60
Ditto, ,, ,, (*b*) Fig. 17	—	P_3	0.294	0.482	8.4	−0.0478	60
Ditto, ,, ,, (*c*) Fig. 17	—	P_3	0.294	0.482	8.4	−0.0478	60
Ditto, polygonal ring	—	P_4	0.294	0.470	4.5	−0.0507	60
Ditto, ditto	—	P_5	0.257	0.478	6.6	−0.0132	60
Body only; cylinders removed and holes papered	—		—	—	—	—	—
"Lynx," engined monoplane (7 cylinders), *without wings* ...	7.60		—	—	—	—	60
		A	0.263	0.482	8	0.0	60
		A	0.263	0.482	8	−0.0395	60
		A	0.263	0.482	8	−0.0395	60

PPENDIX.

SERVATIONS OBTAINED AT THE N.P.L.

. Dimensions are given in engine diameters (the over-all diameter of the engine veen centre line of cylinders and trailing edge of ring (and is positive when trailing ront of centre line).

z.	Speed of test: V, ft./sec.	Drag (lbs. at 60 f.p.s.) R_0	R	$\Delta R = R_0 - R$	R/R_0	Remarks.
	60	1.240 (mean)	—	—	—	
5	60	1.252	1.043	0.209	0.833	
33	60		0.861	0.391	0.688	Ring cut to fit round rockers.
08	60		0.883	0.369	0.705	,, ,, ,,
17	60		0.893	0.359	0.697	,, ,, ,,
1	80	1.216	0.952	0.264	0.782	
17	80		0.864	0.352	0.710	
08	80		0.906	0.310	0.745	,, ,, ,,
08	60	1.230	1.568	−0.338	1.288	,, ,, ,,
08	60	1.230	0.803	0.427	0.656	Ring cut to fit round rockers, but slots so formed in outer surface of ring covered with paper patches.
58	80	1.216	0.768	0.468	0.631	Ring cut to fit round rockers.
58	80		0.777	0.439	0.639	,, ,, ,,
58	80		0.733	0.483	0.603	,, ,, ,,
58	60	1.252	0.633	0.619	0.505	,, ,, ,,
	60	—	0.211	—	—	
	—	0.683	—	—	—	No airflow through helmets.
75	75	0.683	0.552	0.131	0.808	
4	75	—	0.495	0.188	0.725	
5	75	—	0.583	0.100	0.854	
	60	1.230 (mean)	—	—	—	
13	90	—	0.627	—	—	
	80	1.209	0.635	0.574	0.525	Ring cut away to fit round rockers, which were faired into outer surface with ¼in. plasticene fillets.
	70	—	0.664	—	—	
	65	—	1.333	—	—	
	60	1.223	1.466	−0.243	1.20	N.B.—*Large scale effect.*
	40	—	1.628	—	—	
90	60	1.223	0.705	0.518	0.576	Ring cut away; with fillets.
32	60	1.223	0.669	0.554	0.547	,, ,, ,,
93	60	1.223	0.642	0.581	0.525	,, ,, ,,
			0.733	0.490	0.599	,, ,, without fillets.
90	60	1.223	0.717	0.506	0.586	,, ,, ,,
21	60	1.235	0.659	0.576	0.533	,, ,, with fillets.
78	60	1.223	0.773	0.450	0.632	Ring cut away; surface papered.
78	60	1.223	0.701	0.522	0.573	Outer surface unbroken.
956	60	1.223	0.548(?)	0.675	0.448	,, ,,
956	60	1.223	0.945	0.278	0.772	Outer surface unbroken; section made symmetrical with fairing.
36	60	1.223	0.487	0.736	0.398	Outer surface faired.
78	60	1.223	0.485	0.738	0.397	,, ,,
obtained with any model tested.						
78	60	1.223	0.520	0.703	0.425	
78	60	1.223	0.588	0.635	0.481	
78	60	1.223	0.669	0.554	0.547	
97	60	1.223	0.533	0.690	0.436	
32	60	1.223	0.524	0.699	0.428	
	—	—	0.191 (mean)	—	—	
	60	0.423	—	—	—	With nose fairing and spinner.
	60	0.423	0.297	0.126	0.702	Ring cut away; outer surface papered.
95	60	0.423	0.286	0.137	0.674	,, ,, ,, ,,
95	60	0.423	0.254	0.169	0.601	,, ,, ,, ,,

"Lynx," engined monoplane (7 cylinders), *without wings* ...	7.60		—	—	—	—	60
		A	0.263	0.482	8	0.0	60
		A	0.263	0.482	8	−0.0395	60
		A	0.263	0.482	8	−0.0395	60
		With small cowls behind cylinders, allowin					
Ditto	—	E_1	0.263	0.461	11	0.0	60
		E_2	0.263	0.468	5	−0.0197	60
		E_3	0.155	0.480	10	+0.079	60
Ditto, cylinders cowled with individual helmets having airflow through	—		—	—	—	—	60
Ditto, *with wings*	—		—	—	—	—	60
Ditto, with helmets as above ...	—		—	—	—	—	60
Ditto, without helmets, with ring ...	—	E_2	0.263	0.468	5	−0.0197	60

			Axial position x, measured from nose of crank case to leading edge of ring.				
"Siskin-Jaguar" (14 cylinders), body, windscreen, two gun slots and exhaust manifolds; no spinner (ungeared engine) ...	9.0		—	—	—	—	60
Ditto	—	SJ_3	0.278	0.497	11	0.0478	60
		SJ_4	0.278	0.497	6	0.111	60
		SJ_5	0.278	0.497	1	0.103	60
Ditto	—	SJ_6	0.333	0.489	5.5	0.0944	60
Ditto, with spinner	—	SJ_6	0.333	0.489	5.5	0.0967	60 90
		N.B.—Reduction due to spinner when no ring					
Ditto, no spinner, polygon	—	SP_1	0.333	0.545 to corners	8	0.111	60
Ditto, ditto, ditto	—	SP_2	0.389	0.538	6	0.0866	60

	Diam. of Engine on Model (ins.)	Ring.	Axial Position x.	Speed of Test.	Angle of Thrust Line.	Lift (L_0)	Drag (D_0)
*"Crusader," complete machine with all normal fairings ... ... (see D, Fig. 16)	12	—	—	60	0	3.622	2.257
		—	—	—	5	16.92	2.855
		—	—	—	10	27.26	5.066
						L	D
Ditto	—	H_4	0.0283	60	0	3.60	1.628
		—	—	—	5	17.219	2.338
		—	—	—	10	28.818	4.86 4.90
Ditto	—	J	0.0283	60	0	3.81	1.996
		—	—	75	0	3.88	1.738
		—	—	80	0	3.79	1.72
		—	—	80	5	17.41	2.28
Ditto, engine removed, holes papered	—	—	—	60	0	3.584	1.243
Ditto, dummy cylinder helmets added	—	—	—	60	0	4.00	1.676
		—	—	60	5	17.815	2.316
Ditto, ditto	—	A	0.135	80	0	4.00	1.507
		—	—	80	5	17.85	2.099
Ditto, ditto	—	F_2	0.124	60	0	3.757	1.506
		—	—	60	5	17.635	2.350
Ditto, ditto	—	H_4	0.129	60	0	3.844	1.621
		—	0.110	60	0	3.776	1.621

* N.B.—"*Crusader*" *Model*.—The results given for this model are intended to illustr
the actual figures should not be regarded a

-	60	0.423	—	—	—	With nose fairing and spinner.
	60	0.423	0.297	0.126	0.702	Ring cut away; outer surface papered.
395	60	0.423	0.286	0.137	0.674	,, ,, ,, ,,
395	60	0.423	0.254	0.169	0.601	,, ,, ,, ,,
s, allowing passage of air, similar to those shown at C, Fig. 16.						
	60	0.423	0.267	0.156	0.631	Rockers faired into ring.
97	60	0.423	0.258	0.165	0.610	
79	60	0.423	0.301	0.122	0.712	
-	60	0.423	0.223	0.200	0.527	See B, Fig. 17, for helmets.
-	60	0.532	—	—	—	
-	60	0.532	0.373	0.159	0.701	
97	60	0.532	0.376	0.156	0.707	

ition x, from nose case to ge of ring.						
-	60	1.180 (mean)	—	—	—	
78	60	1.184	0.714	0.470	0.603	These are for the best axial positions tested.
1	60	1.184	0.668	0.516	0.564	
3	60	1.184	0.785	0.399	0.663	
944	60	1.176	0.593	0.583	0.504	
67	60	1.184	0.589	0.595	0.497	
	90	1.176	0.545	0.631	0.460	
en no ring is present = 0.160 (at 60 f.p.s.).						
11	60	1.184	0.629	0.555	0.532	
866	60	1.184	0.592	0.592	0.500	

Drag (D_0)	L_0/D_0				
2.257	1.605	—	—	—	
2.855	5.93	—	—	—	
5.066	5.38	—	—	—	
D	L/D	D/D_0	ΔD	$\Delta L/D$ $(=L/D - L_0/D_0)$	
1.628	2.21	0.722	0.629	—	
2.338	7.36	—	0.517	1.43	
4.86	5.94	—	0.18	—	
4.90	5.98				
1.996	1.91	0.884	0.261	—	
1.738	2.23	0.798	0.440	—	
1.72	2.20	0.796*	0.440*	—	*Assuming $D_0 = 2.16$ at 80 ft. p. sec.
2.28	7.64	—	—	1.40	
1.243	2.88	—	—	—	
1.676	2.39	0.743	0.581	—	
2.316	7.70	—	—	1.77	
1.507	2.65	0.698*	0.64	—	Rings in addition to helmets.
2.099	8.50	—	—	2.26	
1.506	2.49	0.668	0.751	—	
2.350	7.50	—	—	1.57	
1.621	2.37	0.719	0.636	—	
1.621	2.33	—	—	—	

l to illustrate the effect of rings; the model itself had had considerable use and regarded as accurate data for this machine.

order of two-thirds the drag of the body and engine only. This looks as if the ring should be securely anchored, as if it came adrift it would not be blown backward but forward into the screw.

Another point already mentioned concerns the use of rings of very thick symmetrical section. These, on the model scale at least, are very sensitive to their exact position in relation to the engine. There is one case on record in which such a ring was tested on full scale with certain modifications in position, etc., made necessary by constructional considerations. In the result no improvement in performance was obtained, although it was not impaired, and certain other benefits were obtained. As a check on this a similar test was made on the model embodying the modifications which had been made on full scale, and only a very small reduction in drag was observed, whereas the original arrangement was quite satisfactory.

Some Full Scale Results

On the other hand, full-scale tests with sections which in addition to being less sensitive were easier to fit without modification have been fairly consistent in bearing out the results of these model tests. In particular, tests both at Armstrong Whitworth Aircraft, Limited, and at Martlesham Heath have shown an increase in speed of about 7 to 9 miles an hour on a Siskin Jaguar machine. Other results include satisfactory tests on a light machine with 5-cylinder engine, mentioned in Major Green's paper, and an increase of nearly 5 m.p.h. on a large twin-engined machine with interplane engine nacelles.

A further result which may be mentioned is that of a twin-engined monoplane having a Lynx engine on each wing. In addition to the reduction of engine drag which produced an increase of 7 m.p.h. near the ground, in this case the maximum lift of the wings was also improved, the joint effect giving an increase of several thousand feet on the ceiling. Without the rings the disturbance over the wings caused by the engines was very considerable, enough, in fact, to render the original performance quite inadequate for the work for which it was designed.

In conclusion, I would like to thank those firms who have allowed me to refer to the full-scale results which they have obtained, and I hope that all those who can do so will contribute their full-scale experience to the discussion.

Discussion

The Chairman (Mr. McKinnon Wood, in the absence later of the Master of Sempill): He was inclined to think that the Townend ring was the most interesting and useful invention in aerodynamics since the Handley-Page slot, which it resembled somewhat. Mr. Townend was to be congratulated upon the unusual rapidity with which his invention had been put into practical use, and it was perhaps symbolical of that that Major Green had followed close on his heels to describe the progress which had been made by a designer of aircraft in the use of the ring. He believed Mr. Townend had found, as had also those who were working at the Royal Aircraft Establishment, not only that the Townend ring made a considerable reduction of drag, but that it brought about a reduction very nearly as great as we had been able to obtain by any other engine cowling. On first sight of the device it seemed incredible; but it was so. Further, when one bore in mind the advantage from the point of view of accessibility which the Townend ring possessed, and its simplicity, it would probably be agreed that, on balance, the Townend ring was ahead of other forms of cowling. As one who was responsible for a certain amount of aerodynamic research, the Chairman urged that all should push on and try to reach the next stage in the reduction of drag of air-cooled aircraft engines, because he could not help feeling that present arrangements represented only a half-way stage; *i.e.*, they

would last, perhaps, for the next ten years, and it seemed to him that Mr. Townend's ring held the field in this stage.

Mr. J. D. NORTH: He held that the Townend ring was the second of the only two aerodynamic inventions which had been made in the last decade. Mr. Handley Page's slot had enabled aeroplanes to go slower, and Mr. Townend's ring had enabled them to go faster. Mr. Townend should receive a special testimonial from the manufacturers of radial engines, because his invention had entirely re-oriented the whole outlook on the economy of this type of motor. Messrs. Boulton and Paul, with the assistance of Mr. Townend, had done a considerable amount of wind channel and full-scale experiment with the ring, on lines somewhat different from those described by Major Green, because they had been interested in the mounting of engines on nacelles which in their turn were on a wing. They knew from painful experience that what was a favourable arrangement at small angles of lift was not necessarily favourable at large angles of lift—that there was what he had ventured to call an induced interference, which caused a rapidly increasing induced drag with increasing incidence—and the Townend ring had enabled them to overcome that difficulty entirely. But it had been necessary to use rings of proportions different from those which were based on the free air condition. For example, on the question of chord, a ring which finished at the centre line of the cylinder was perfectly satisfactory on a fuselage tested by itself, but when the ring and the engine were near to the leading edge of the wing the increase of the chord up to a certain fairly critical point maintained a low drag over a wide range of incidence, and yet the increase of chord was critical in the sense that making it larger produced no difference. It was a remarkable thing that it should be so critical. Of course, he did not think it was safe to make any sort of generalities and to say that, because one proportion of chord was critical for one combination, this criterion was of general application. For example, Major Green had mentioned a case in which the wind channel had indicated that rounding off the sharp cliff edge slightly increased the drag; in another combination it was found that the rounding off of the sharp edge cliff quite appreciably reduced the drag. Those results were not necessarily inconsistent—they were not contradictory; they meant that the conditions were quite different, and we were not yet in a position to postulate the ideal conditions. Messrs. Boulton and Paul had certainly found, in some of their wind channel experiments, confirmed by full-scale experiments, that there had been no change of cylinder temperature due to the fitting of the ring, and the wind channel tests had indicated definitely increased air velocities over the cylinders. They had not found it impracticable to get a satisfactory ring embodying the exhaust in front, and it was a curious thing that the large number of exhaust pipes, the 18 which were used on a 9-cylinder engine, did not make any difference—or, at least, any difference within the order of wind channel accuracy—to the drag determination. It was very critical where the exhaust pipe entered the ring. If the connecting pipes were brought too far forward they did cause a disturbance. Similarly, one came generally to the conclusion that what was done, within reason, inside the ring did not make a great deal of difference. He had been rather surprised to note that the helmeted "Crusader" had shown such an improvement over the un-helmeted; whether that was general, or whether a different type of ring might have produced the same effect with the un-helmeted cylinders, he was not able to say. So far as the N.A.C.A. cowling was concerned, he had had the opportunity of discussing it both at Langley and at Wright Field—at which latter place it was called the "Wright Field" cowling—and there was no doubt that that type of cowling was entirely different, and that the inventors were not in the least aware of the principle of Mr. Townend's ring. In fact, he had ventured to give them a description of Mr. Townend's theory, and they were very interested and, he believed slightly incredulous. There was a certain fundamental difficulty which

it was well to point out in expressing the results. If one expressed them in the form of R/R_0, if one called it a figure of merit, so much depended upon what one started with. In the case of engines mounted on wings one obtained the figure of 0.23, but one washed out some induced interference. It was difficult also to express what one meant in terms of added miles per hour. One American machine had shown an increase of 17 m.p.h. with N.A.C.A. cowling, largely due to a reduction of induced drag and increased propeller efficiency and extra r.p.m. due to the individual characteristics of the particular aeroplane, and the reduction of drag was not better than had been obtained with the Townend ring. One other difficulty was that with wind channel models of quarter scale, with engines, if one made them representative, there was a large number of parts subject to scale effects, and there were difficulties in interpreting wind channel results of that kind. Fortunately, however, if it were true that adding and subtracting a fairly large number of struts and other obstructions inside the ring made little difference, that might be enough to cover other uncertainties.

Mr. SIDDELEY: As a constructor and manufacturer, he congratulated Mr. Townend and expressed indebtedness to him for having substantiated his (Mr. Siddeley's) belief that the radial air-cooled engine would in time prove itself to be equally as fast as any other type. The fact that they had attained a speed of over 200 m.p.h. with a standard type of aeroplane, he said, showed that they were rapidly approaching the time when there would be less and less difference between the water-cooled engine, with its necessary radiator, and the air-cooled engine. He believed they had reached a very important stage in the evolution of things, and he looked forward to the next stage, in which they would attain something vastly speedier.

Mr. REYNOLDS: The problem had been considered more or less from the commercial point of view. As each body appeared to require a different ring, or a different angle of ring, it had seemed very difficult to accommodate one or a few rings to a variety of fuselages having different engines. However, tests were made with various rings, and two rings were selected which gave results which were not exceptionally good, but not bad. One ring was about 17½ inches chord, and one about 12½ inches. Both these rings had been tested full scale, and the results were certainly very promising, and he considered that a great step forward had been achieved. A further stage had since been reached, for there had been developed a streamline exhaust collector, which obviated any chance of drag due to stub pipes projecting beyond the ring, and also obviated any chance of upsetting the air flow from the ring itself. That was important, because during observations on a machine it was very noticeable how the air was smoothed out over the rear cockpit as the result of the use of the ring. It was decidedly lumpy and seemed to come from all directions when the ring was not used, but with the ring it appeared to be quite smooth. The manufacture of the ring was a rather difficult problem, because one had to overcome small periods of vibration, which the ring took up and rather amplified. If the brackets were made absolutely solid, something would break, and if they were too floppy something would break. Therefore, a compromise was made, the ring being given a certain amount of damping, which could be adjusted, and in that way practically all the troubles seemed to have been overcome. Except for one period, which could be passed very easily, no trouble whatever had been experienced.

Lt.-Col. H. STEENSMA (Engineer-in-Chief of the Royal Dutch Air Force): He had had the pleasure of meeting Mr. Townend in Holland, had become interested in the Townend ring, and had since carried out tests on four different types of machine. From the results attained so far, he was certainly glad that those tests had been started, and he was sure they would be continued. On a single-seater fighter, fitted with a Jaguar engine, there was a difference of

10 per cent. in the speed attained at ground level with and without the ring. One would have thought that at 15,000 ft. the difference would have been greater, but that was not the case. The speed at 15,000 ft. was 330 kilometres per hour with the ring fitted, and 315 kilometres without the ring. The difference in the speed at ground level as the result of the use of the ring—the engine was supercharged—was 20 kilometres. Referring to another machine, a two-seater, with a Jaguar engine, he said he had not admired very much the manner in which the engine was put in; therefore, he had fitted a Townend ring, and had expected a very much higher speed as a result, but there was absolutely no increase of speed. The only result noticed was that the handling of the machine was much improved when the ring was fitted. That indicated the importance of the combination of the ring and the shape of cowling; there should not be a big gap. The ring had been used on other machines, but the time available so far had not been sufficient to enable exhaustive tests to be carried out, and he was unable to give figures. He congratulated Mr. Townend upon his invention, which was one of the most important and interesting he had heard of during the last ten years.

Mr. A. DAVENPORT: On the "Jaguar" and "Panther Wapiti," his Company were proposing to use the cowl and streamline collector ring developed by the Armstrong Siddeley Company, as this type of cowl appears to give the results claimed for it. Their own development work had been in connection with a 9-cylinder engine, and they had tackled the problem rather from the point of view that it was necessary to have the ring combined with an exhaust collector. They had actually tested one in the wind channel, with a collector in front and a series of helmets over the cylinders, joined into the inter-connecting cowl-work, and the wind channel tests, if they were correct, showed that 70 per cent. of the engine drag was recovered, and it appeared as though there would be a 5 per cent. increase in speed. The early experiments with the streamlined rings in front were disappointing. The Bristol Company had developed one at the same time, and both had been tested full scale on the Wapiti. Comparisons were made with and without the exhaust ring fitted, but there was no measurable difference in the performance of the aircraft.

Mr. RELF: He confessed that at first he had had some slight misgivings with regard to the use of the ring, because he had thought there might have been some serious scale effects. It was known that a long cylinder exhibited a very important critical region round about a Reynolds number of five millions, where the drag dropped very rapidly. He had thought it possible that the projecting cylinders on the body of an aeroplane might also have a critical speed in that neighbourhood, and therefore, that the drag at full scale Reynolds number might be less than was thought, so that there was not so much to gain on the full scale as on the model. That had been disproved, however, in two ways. There was fairly reliable full-scale evidence that the ring did as much on the machine as on the model. Secondly, Mr. Townend had actually made the experiment in the duplex wind channel, in which he had used a short cylinder of sufficiently large diameter to be at that critical Reynolds number, and had shown that when it was very short the scale effect was very much less marked than with a long cylinder. It was well known that the flow round a body was fairly stable in the neighbourhood of the nose, where the stream was still accelerating, but it became less stable near the maximum diameter and still less stable near the tail end. If one introduced interference near the nose it had little effect; if the same interference were introduced at the maximum diameter it produced greater effect. The radial engine constituted a very serious disturbance, and actually succeeded in breaking up the flow round the body, although it was placed in a fairly stable region of flow. The ring controlled that flow and forced it back on to the surface of the body, so that the flow

behind the engine was very nearly as good as if the engine had not been there. If they could actually make the flow on the after part of the body perfect, there was no reason why there should be much more drag than the mere skin friction of the cylinders and the rings themselves, which was very small. He believed that this was the simplest way of regarding the behaviour of the ring.

Mr. W. S. FARREN: Those whose interests are mainly concerned with aerodynamic research might envy Mr. Townend his luck—though in no ungenerous spirit—but they must all acknowledge that the rapid development and application of his invention was ample evidence of his remarkable appreciation of practical requirements.

The Townend ring had been helped, not only by the simplicity which Mr. Siddeley had praised, but also by the great advantage which it had over the N.A.C.A. cowling or any similar arrangement, in that it was almost obvious that it would allow the engine to be cooled satisfactorily. Major Green had suggested that almost any cowling reduced cooling, and no doubt he had definite evidence of that, but it seemed that it ought to be possible, with such a device as the Townend ring, so to direct the air that it would actually improve the cooling. The amount of space available for the flow of air had made one confident that the cooling would be satisfactory and that the full development of the device would not be hampered by difficulty with the engine. It was because of the absence of that confidence that the 1917 experiment in this country, referred to by Major Green, had not developed into the equivalent of the N.A.C.A. cowling. The perfection of that cowling had been possible because, although the crucial problem was to make the cooling adequate, the Americans were able to carry out experiments in their 20-foot wind tunnel. He did not hesitate to say that if Mr. Townend's invention had been of the same type, *i.e.*, one in which the cooling was the crucial feature, we should be still struggling with the inconvenience of not being sure whether an aeroplane on which the experiments were to be carried out would succeed in getting back with its engine intact. Advance in such matters was much more rapid when a large wind tunnel was available, and he urged those concerned with these problems to lend their support to the efforts that were being made to provide this country with a tunnel in which experiments could be carried out with the engine running.

The Townend ring, which, as Mr. Relf had explained, restored the air flow which had been disturbed by the presence of the engine, was really a special example of a general type of development. We were at last discovering that we could induce air to go where we wanted it to go, if we took the proper steps. It was not sufficient merely to leave a space open for the air, because in many cases it would not find its way there unless we provided " finger posts " to direct it. It seemed that there were many applications of that principle. He was interested in the remark of Col. Steensma, that in one case, although the speed of a machine was not increased as the result of the use of the ring, the handling of the aeroplane was improved. It would seem that some of the troubles experienced in connection with control at the tail might be eliminated, or at any rate reduced, if it were realised that an improvement in the whole flow at the back of the body could probably be brought about by the application of the principle which Mr. Townend had applied so ably in the Townend ring. It was the impression of many that, in order to make air turn a corner, all that was necessary was to provide the corner. It had been realised many years ago in Germany that, to make air turn a corner without the loss of a large amount of energy in turbulence, one must provide aerofoils suitably disposed. That device had made possible the Göttingen closed circuit wind tunnel, a type now being adopted more and more widely. We ought to realise that it was the key to every problem involving the direction of air to special places. The loss of energy involved was probably little more than that due to the skin friction of the aerofoils.

Mr. J. S. L. Oswald: There are in use three classes of cowling which are used to reduce the resistance of radial air-cooled engines.

(1) Standard faired type + spinner.
(2) N.A.C.A. cowling.
(3) Townend ring.

It is accepted now that the future lies between (2) and (3). Further, provided the results obtained are equally good, simplicity always wins the day. The simplicity of the Townend ring makes it superior to the N.A.C.A. type cowling.

To produce a successful type of N.A.C.A. cowling, elaborate wind tunnel tests with engine and airscrew running are necessary. A small wind tunnel can be used to obtain the approximate data for a suitable Townend ring, and since the latter can be beaten out in a few hours, it is relatively inexpensive to try out full scale several rings until the most satisfactory is obtained.

Messrs. Handley Page, Ltd., fitted a Townend ring to their "Guggenheim" Competition Aircraft, which was fitted with a "Mongoose" engine. Prior to fitting the rings, streamers indicated that at certain points there was severe turbulence. The fitting of the Townend ring immediately straightened out the flow, this being again indicated by streamers, and the feel of the airflow while flying in the rear cockpit.

Rings whose incidence are indicated by the figures 0°, −2°, −5° and −10° and −5° with 50 per cent. increase in chord were tried. It was found full scale that the incidence was not critical within 2 to 3 degrees and that the 50 per cent. increase in chord provided no appreciable gain. The final ring adopted was −2° 13.5 in. chord, and gave a percentage increase in speed of the order indicated by the lecturers.

The cooling of the engine was improved and weight saved, since the faired type of cowling plus spinner was removed and the engine left uncowled up to its cone ring.

Major Green quotes steel as the material for the rings; Messrs. Handley Page used 16G duralumin finally and found the ring successfully withstood vibration.

A thinner gauge was used at first, but vibration of the trailing edge of the ring was very pronounced. A flight was carried out with the thin gauge ring strengthened on the inside by small channels. It was found that these channels had lowered the gain in speed, which is contrary to the view expressed by a previous speaker that anything in reason may be done to the under-surface of the ring.

Lt.-Col. J. D. Blyth: Is there any difference in the cooling of an aeroplane engine with a single bank of cylinders and one with a double bank of cylinders when a Townend ring was fitted? He understood that the cooling of a Jaguar engine, which has a double bank, was satisfactory, but reports on the N.A.C.A. cowling with a Wright Whirlwind engine, which has a single bank of cylinders, stated that deflector plates had to be fixed between the cylinders to ensure adequate cooling. He suggested that the difference in cooling might be due either to the difference in air flow or else to the fact that an engine with a single bank of cylinders having a smaller number of cylinders, had naturally a smaller cooling area per horse-power. Did this apply to the Townend ring?

Secondly, he asked if it were not possible that the ring or the adaptation of it, might be used to reduce the drag of a radiator by stopping the turbulence of the air spilling over the edges.

Finally, was the increased speed which was attained when the ring was fitted due entirely to decreased drag or was it due partly to the reduction in body-airscrew interference and consequent increase in r.p.m. and possibly airscrew efficiency?

Mr. IRVING: One application of the principle of the ring which had been considered at the National Physical Laboratory was in connection with the mooring of airships. It had occurred to some members of the staff there that an airship might be brought up to the ring against the wind and finally sucked into the ring, without making actual contact. That idea, however, was soon dropped, because it became evident that it would not work if the direction of the wind changed. The direction of the wind was capable of moving many degrees in a few seconds, and as soon as the wind yawed the airship would get away. Commenting on the reference made, in the last section of Mr. Townend's paper, to a twin-engined monoplane in which, " in addition to the reduction of engine drag, the maximum lift of the wings was also improved, the joint effect giving an increase of several thousand feet on the ceiling," Mr. Irving said he would like to be re-assured that there was definite evidence of the increase in maximum lift because the connection between maximum lift and ceiling was not clear to him. As Mr. Townend had explained, the ring worked owing to the lift on it. If there were a lift and an effective angle of incidence on the section of the ring at normal flying speeds, then at the stall one would expect at any rate some portion of the ring to be stalled, and at the stall he imagined there would be a considerable increase of drag rather than a decrease, due to the ring. That, so far from being a disadvantage, might be an advantage, in that at the stall the gliding angle would be made much steeper, and the advantage would arise in making an approach to the landing ground. With regard to weight, on all counts of course, it was important to keep it down, but it should be borne in mind particularly in relation to spinning. He believed that the disposition of the ring in relation to the position of the centre of gravity of the machine was always such that in a spin, there would be an increase in the pitching inertia term due to the ring, *i.e.*, there would be an increased tendency for the machine to stay in a spin. He did not think that effect would be very great, but it was worth bearing in mind.

Dr. A. P. THURSTON. He welcomed the papers because they supported a proposition which was first enunciated by him, namely that a " rider " plane or " rider " body could be used to alter or " interfere " with the aerodynamic properties of another plane or body for various purposes, such as improving the stability, increasing control, amplifying the lift, reducing the resistance, securing relative motion, etc.

He further pointed out that in " Flight " of 20th November, 1914, would be found his publication of work on a " rider " plane in front of a main aerofoil.

The apparatus used in these experiments is illustrated in Fig. 1. The main plane was mounted on a " turn table " in the side of the wind tunnel so that it could be rotated to any angle in the tunnel, and the " rider " plane was rotatably and adjustably mounted vertically and horizontally on arms or outriggers carried by the main plane. Thus the " rider " plane could be adjusted to any position and angle relative to the main plane, which itself could be adjusted to any angle. Diagrams of the distribution of pressure over the main plane and " rider " plane were obtained for a number of positions of the " rider " plane with a large number of angles of the main and rider planes.

These experiments showed, see Figure 2, that :—

1. The lift of the main plane increased as the width of the " gap " increased for all inclinations of the " rider " plane.
2. That the increase of lift took place on the suction side of the main plane, and
3. That alteration of the angle of the " rider " plane altered the lift of the main plane in a similar way to that due to variation of the angle of the main plane alone.

He emphasised that these readings and results were obtained and published before the war.

A number of photographs were then shown, illustrating the use of the alula or " thumb " on a bird's wing in different conditions of flight.

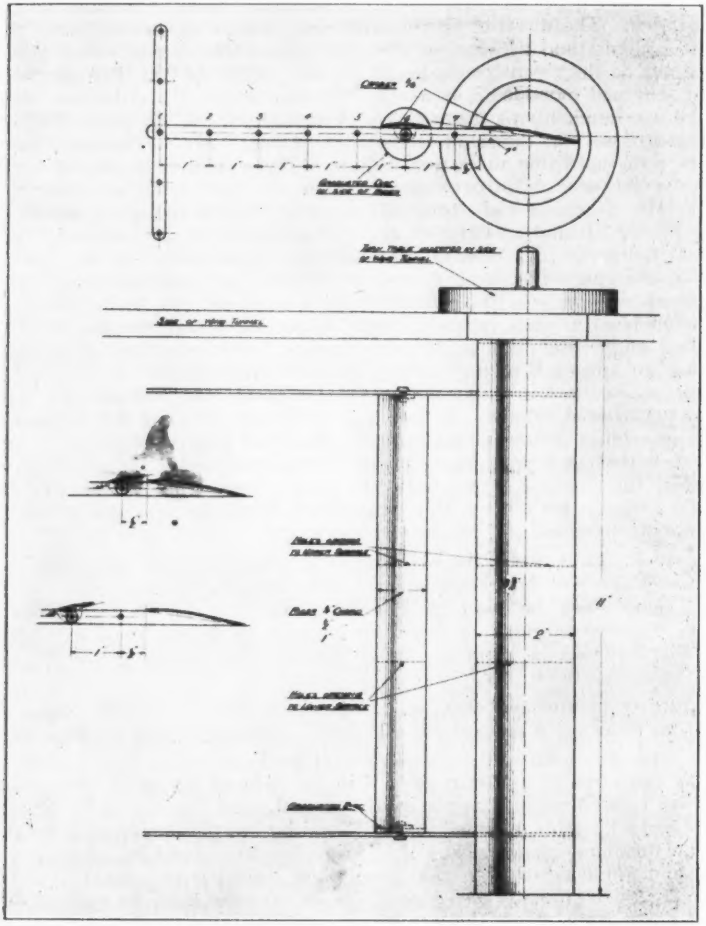


FIG. 1.

Figure 3, taken by Mr. Charles Kirk, and published in 1907 in " Wild Birds at Home," Messrs. Gowan & Gray, Limited, shows a kittiwake gull in an extremely awkward position—a climbing turn. An alula was extended on one side to form a gap, and was quite closed on the other; its purpose apparently being to prevent dropping on one side during the turn. Dr. Thurston expressed the opinion, as the result of his many observations on bird flight and dissections of birds' wings, that the alula was used by the bird not only to prevent stalling, but also for

lateral control. He was also of the opinion that the bird's alula has a combined rudder and aileron effect.

Figure 4, taken from his Patent Specification, dated 14th December, 1920, shows Dr. Thurston's method of fitting a " rider " plane to an aeroplane so as to obtain an alula effect to prevent stalling and to obtain lateral control. Figures

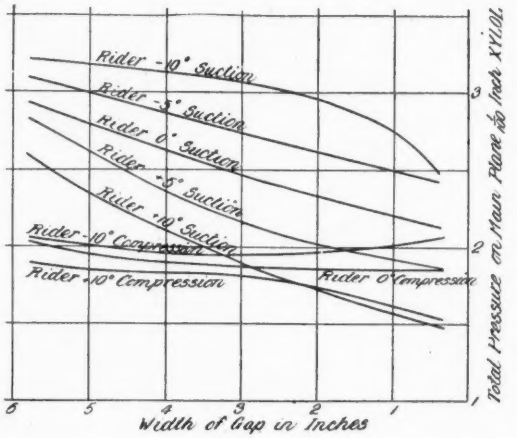


FIG. 2.

2a and 3a of this Figure, show a method of mounting the alula. The inclination of a lever x^1 may be controlled from the cockpit in order that, when the plane is " stalled," the alula effect may be at once upset, thus enabling the machine to be laterally controlled in the " stalled " position. On the other hand, when the machine is flying at a normal angle, it may be steered by increasing the negative inclination of the " rider " on one side, as shown in Figure

FIG. 3.

3a, thereby increasing the resistance and decreasing the lift on that side, and giving a correct amount of rudder and banking for the turn. Similarly by decreasing the negative inclination of the " rider " plane on the other side the resistance and the lift, in certain conditions, may be respectively decreased and increased.

It may be remarked that these " rider " planes were found to open automatically when the inclination of the main plane exceeded a certain amount.

A.D. 1920. Nº 21496/21. FIVE SHEETS. SHEET 5.
THURSTON'S COMPLETE SPECIFICATION ORIGINAL

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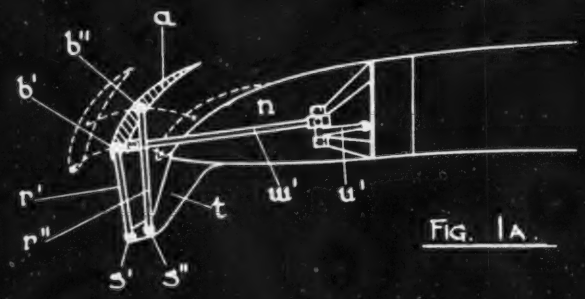


FIG. 1A.

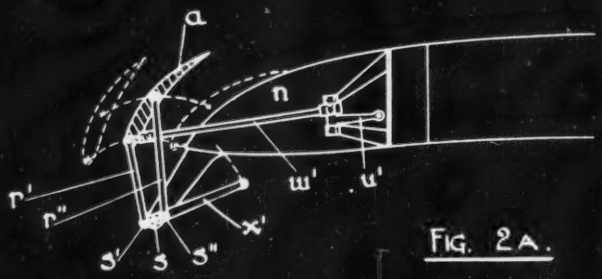


FIG. 2A.

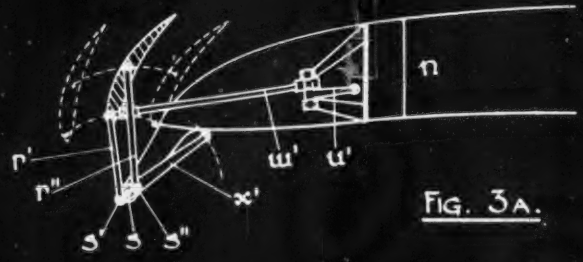


FIG. 3A.

H. T. Thurston

FIG. 4.

Another illustration of the use of " rider " planes is given in Figure 5. In this case a cylinder is provided with a " rider " plane which could be moved to any distance from it and rotated at any angle. As the cylinder itself could be turned on its own axis, the lift and drag of the combination could be quickly taken for a large number of dispositions. The diagrams illustrate the influence of " rider " planes in varying the drag and lift at various angles and distances

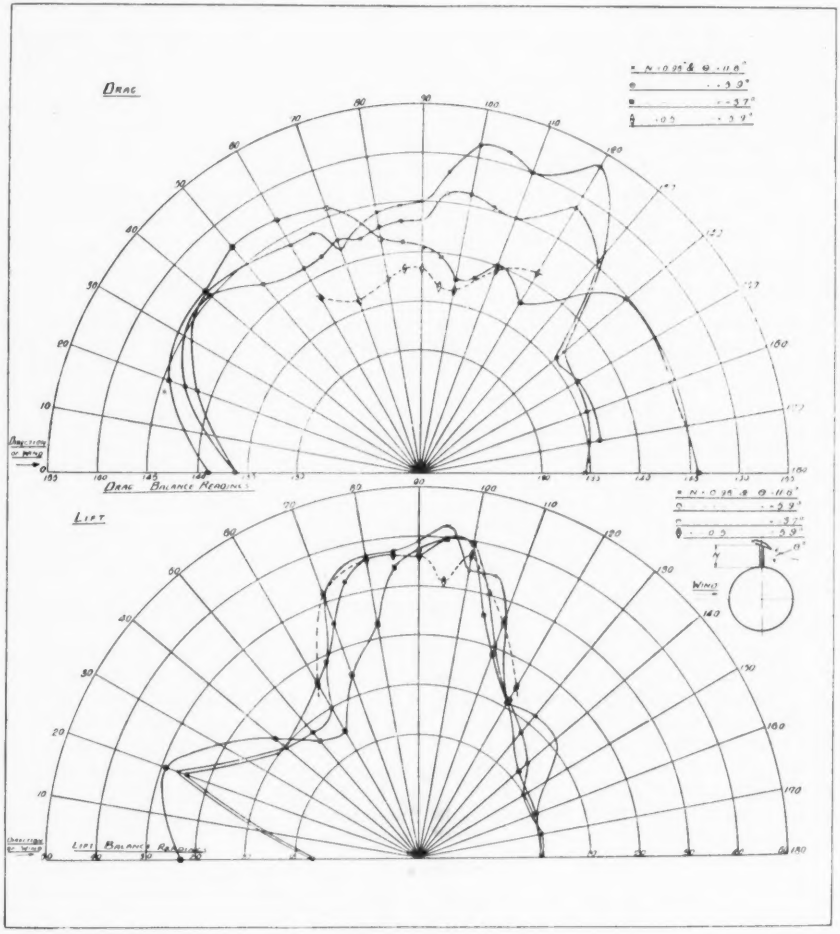


FIG. 5.

from the body. Referring to the lift curve it will be seen that there are two positions of the " rider " giving considerable increase of lift, namely, between angles of 70° and 110° and in the neighbourhood of 20°, from the line of the wind. The minimum drag appeared to be when the " rider " was in the line of the wind, or between angles of 70° to 100°. By utilising such an arrangement in front of the wheels of an aeroplane it would appear possible to make the wheels

give a lift and also to rotate in the right direction so that the rotation would reduce the drag.

It was obvious that there were dozens of applications of this principle of associating the " rider " plane or body with the main plane or other body. And he regarded the application of this principle as providing a most fruitful source of future development in regard to aircraft. For considerably over fifteen years he had been emphasising the matter publicly, and it was gratifying to know that at last the application of the principle was being appreciated.

Mr. W. G. A. Perring (*communicated*): Some cowling tests have recently been carried out at Farnborough. These tests have been made on a one-fifth scale model Bristol Bulldog and investigated the cowling of a Jupiter VII air-cooled engine. The tests were primarily carried out to investigate the possibilities of fitting the Jupiter VII with a helmet type cowling, but the work was extended and tests were made with a ring type cowling similar to the N.A.C.A. cowl, and also exhaust and thin plate Townend rings.

Drag tests without airscrew showed that the helmet cowl, ring cowl, and thin polygonal type Townend ring all resulted in the same reduction of drag, viz., a reduction of approximately 20 per cent. of the drag of the whole uncowled aeroplane. The drags expressed in lb. full-scale at 100 feet per second are given in the following table:—

Comparison of Drag (lb. full-scale at 100 ft./sec.) without Airscrew. Model Tests at 50 ft./sec.

Model.	Complete model @ 0° wing incidence.	fuselage only.
Model with existing crankcase fairing ...	158	72.8
Ditto, no engine	—	23.5
Helmet cowl	122	—
Ring type cowl	122	—
Townend ring, exhaust type. Ring at −4.0°	168	—
Townend ring, exhaust type. Ring at −8.0°	133	—
Townend ring, thin polygonal type	122	39.5

Over the range of incidence tested the cowlings were found to have practically no influence on the lift.

Tests were also carried out with airscrew, and an analysis of the results suggests that the top speed can be improved about 10 per cent. by the addition of cowling. At climb incidences the model tests with airscrew show for the cowled models only slightly improved rates of climb, but the analysis indicates that the speed for maximum rate of climb is increased by the addition of cowling. The results of the analysis are given in Table II; the results are based on the assumption that the aeroplane is fitted with an airscrew permitting the engine to develop its full throttle power and maximum revolutions at the maximum level flying speed.

TABLE II.

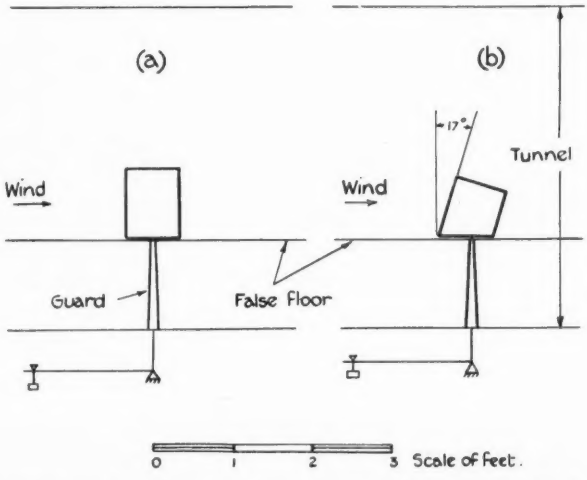
Comparison of Cowled Results expressed as Ratios of the Uncowled Performance.

Cowl.	Maximum level speed.	Rate of climb.	Mean cooling speed past cylinder at level speed.	Mean cooling speed past cylinder at climb.
Helmet cowl	1.106	0.994	0.83	0.87
Ring type cowl	1.103	1.035	0.92	0.95
Townend ring, exhaust type. Ring at −8.0°	1.063	—	0.92	—
Townend ring, thin polygonal	1.102	1.029	0.87	0.92

Tests were also carried out to determine the influence of the various cowlings on the cooling of the engine. For these tests a specially constructed Bakelite cylinder was employed. In this cylinder the barrel fins nearest the head were of mica and had platinum foil attached to both surfaces. Additional strips of platinum foil were also placed on the sides, front, and top of the cylinder head. The foil was connected in series and formed the fourth side of a Wheatstone bridge. During the tests the current and voltage required to keep the Wheatstone bridge balanced and thus maintain the cylinder at approximately 40°C. above the temperature of the surrounding air, were measured. The cylinder was calibrated in open tunnel under conditions similar to those of a cylinder tested in an air blast on the test bed. The calibration was used to determine the mean effective speed of the air passing the cylinder when the cylinder was placed in its correct position on the model. All the forms of cowling tested were found to reduce the cooling; the amount of the reduction being given in Table II, where the speed past the cylinder for the cowled model is expressed as a ratio of the speed found from the uncowled tests.

Reply to Discussion

Mr. Townend: Commenting on the Chairman's remarks, he said that when he had first looked at the ring himself he had felt that it was an excrescence which would not remain there for many years. It certainly looked as though the result of fitting it would be to reduce the speed of the machine. Mr. North had mentioned an important point when he said that the length of the chord should be greater when the engine nacelle was mounted on a wing. His experience confirmed Mr. North's remark that one could take liberties inside the ring which one could not take when the ring was not fitted. In one of his model tests he had tested the effect of the spinner on the Jaguar engine model, and had found that the change in drag due to the spinner was very much greater when the ring was not fitted than when it was fitted. He believed Major Green had given figures which confirmed this result. There were several alterations one could make inside the ring which did not appear to have at all an important



Scale effect on the drag of a very short cylinder projecting from a plane surface.

effect, but which had an important effect when there was no ring. As to scale effect, when Mr. Relf had first mentioned the point to him he had felt that perhaps only half the advantage found on the models would be obtained on full-scale, and had thought that more than likely Mr. Relf was right. He was glad, however, that he was not altogether right, as was shown by the experiment to which Mr. Relf had referred. (Mr. Townend described his tunnel experiment by means of a sketch. Sketch attached.) In the sketch, (*a*) shows a short cylinder mounted close to a wall (false floor), and (*b*) shows a similar cylinder inclined backwards to imitate an engine cylinder projecting from the nose of an aeroplane body. At the critical Reynolds number, the drag coefficient of an infinite cylinder drops to one-quarter of its low scale value; the coefficient for sketch (*a*) drops to about half, whilst that for sketch (*b*) shows no scale effect at all. After this, hope revived and has since been justified by full-scale tests.

Commenting on Colonel Steensma's reference to the results achieved in Holland when the ring was used, he said that 10 per cent. seemed a very large increase in speed. He agreed that each case should be tested individually; the case of failure mentioned by him was interesting, and was probably a case requiring an individual test. Other tests made in Holland were also known to have been successful.

With regard to the early rings referred to by Mr. Davenport as having been tried on a Wapiti both by his Company and the Bristol Company and having produced no improvement in performance, he said that it had a very thick symmetrical section. When he had heard of the result obtained on the Wapiti he had tried a similar ring on his own model. He thought, for one thing, that the angle was wrong. The radius was also too large. When imitating this ring in the model test he had altered the angle, but even so had effected only a 12 per cent. reduction in the drag of the body of the engine, whereas the original test, with the same thick symmetrical section, had shown a reduction of 45 per cent. of body-engine drag. The ring was also very heavy, and it is perhaps surprising that it did not spoil the performance.

Discussing the question of cooling, he agreed with Mr. Farren that it ought to be possible to direct the cooling air so as to improve the cooling. The ring itself must almost necessarily reduce the *speed* past the cylinders to some extent on account of the circulation associated with the " lift " on the section; at the same time the *direction* of the air was changed favourably by the ring so as to become more nearly parallel to the cooling fins and this might more than compensate for the reduced air velocity. Reports from different sources had indicated both increased and reduced cooling according to the particular case tested, though he had not heard of any cases of inadequate cooling except on relatively slow machines. Mr. Farren's remarks concerning " Finger Posts " are very pertinent and express concisely the basic ideas underlying the applications of the ring principle to other cases of turbulent flow. It is a principle which one should always have at the back of one's mind.

He asked Dr. Thurston whether, during his cylinder tests, he had ever obtained a value of overall drag which was less than the drag of the cylinder alone.

Dr. THURSTON said he had not; but the two were practically the same.

Mr. TOWNEND asked if the speed were less than, say, 60 ft. per second, and therefore well below the critical?

Dr. THURSTON said it was.

Mr. TOWNEND said he had experimented with attaching things to cylinders and had obtained some curious results *below* the critical speed, but they had disappeared above it.

Mr. Oswald's remarks bear out very closely the results obtained at the N.P.L. It is interesting to find that the spinner and normal cowling can be so

far removed as to represent, after the ring is added, a net *saving* in weight. Perhaps this removal of cowling may have some bearing on the increased cooling which was also obtained, and it is in any case a confirmation of the fact, already mentioned in the discussion, that liberties can be taken with what lies inside the ring. It may be pertinent to emphasise here that undue liberties should not be taken with the under surface of the *ring itself*, as this interferes with its power to function as an aerofoil.

With regard to Lieut.-Colonel Blyth's suggestion of applying a ring, or its equivalent, to a radiator, it is very likely that the drag would be reduced; at the same time one would expect some reduction of the air speed through the tubes. It was almost certain that the speed through the tubes would not be increased on account of the circulation round the ring section.

With regard to the increase in r.p.m. and possibly airscrew efficiency, these would result from the increase of speed itself. There would be a gain in respect of induced drag also, but all these are ultimately referable to the reduced amount of direct head resistance. In the airscrew tests he had made he had found that, at a given speed of flight, the change in drag due to a ring without the screw was the same as the change in overall thrust with it. It is difficult to see how a ring could reduce interference between the airscrew and the body; if any such effect was present, then a ring should increase the net efficiency of a *streamline* body—airscrew combination. So far no experiments on attaching a ring to a simple streamline shape have suggested such a possibility so far as I know.

Mr. Irving's suggestion that an airship might be moored by means of a ring which did not touch it was made the subject of one or two tests, but as he said the method was only successful at zero yaw.

With reference to the increase in ceiling it would have been more correct to say that the "lift," not the "maximum lift," was improved. The suggestion which it was desired to make was that part of the improvement was due to an increase in lift caused by a smoother flow over the top surface. The overall effect was one of increased L/D, but in this case the increase was probably due not only to decreased D but also to increased L.

The possibility of stalling part of the ring is not so likely as it appears at first sight, since the airscrew thrust is generally greater when the machine's incidence increases above the top speed value, and this tends to unstall the ring by tending to keep the local flow parallel to the shaft. Also the range of angle of the ring section from zero lift (on the ring) to ring stalled is greater than it would be if the ring section were in free air, since the ring itself governs to some extent the local direction of the air passing it. This probably accounts for the fact that the exact angle of the section is not critical.

The model test figures quoted by Mr. Perring are in good agreement with those obtained at the National Physical Laboratory. They confirm the liability of the exhaust type ring section to stall (compare $-4°$ with $-8°$). As well as the fact that such sections cause a smaller reduction of "cooling speed" past the cylinder than the cambered plate sections.

Major GREEN: A 10 per cent. increase of speed, mentioned by Dr. Steensma, was rather surprising, and perhaps that increase was not due wholly to the fitting of the ring. The engine of the machine with which that result was obtained was supercharged; he imagined that the throttle was partly closed and a very small difference in the throttle opening would in itself make some difference to the speed. Therefore he suggested that the figure obtained on the machine having the engine throttle wide open would be more reliable. Mr. Davenport said that they had been successful in making a combined Townend ring and exhaust pipe on a Wapiti aircraft. If it was really successful he was to be congratulated. One reason why he did not like the combined exhaust collector and

ring was that a fair amount of heat was likely to be imparted from the ring to the cylinder heads which one wanted to cool most. Again, the collector became rather big on a military machine and was likely to get in the way of the guns. It was quite likely that the heating up effect of the ring on the engine would only show up after extensive use, but in a general way anything that increased the temperature of the cylinders on an air-cooled engine was best avoided.

With regard to Mr. Farren's remarks, he did not know whether the ring had any appreciable effect on the cooling, but he could say that there had been no trouble as yet with engines to which the ring had been fitted. The cooling had been as adequate since the fitting of the ring as it had been before, but whether the actual degree of cooling was a little more or a little less he did not know.

With regard to Dr. Thurston's reference to making a wheel rotate in the right way, he said he was wondering which was the right way.

Discussing the materials used for the making of rings, up to the present sheet steel had been used. There was no reason why duralumin or aluminium might not be successful, but the ring was generally subjected to bigger forces than at first sight seemed probable, and it was certainly necessary to make a substantial job of it.

Replying to Colonel Blyth, he said he did not see why a ring should make much difference in the cooling of an engine with a single row of cylinders as compared with an engine with two rows. As to the effect of the ring upon spinning, he assured Colonel Blyth that his company had fitted the ring to three or four types of aeroplanes which had been through sustained spinning and he had not noticed any adverse effects. Dealing with the question as to whether the increased speed attained was due partly to the increased speed of the airscrew, he said that when the machine travelled faster of course the speed of the airscrew was slightly faster, but the effect was very small and he had not taken the trouble to separate out that particular effect.

The use of streamers showed how remarkable were the effects of the ring. He had cinematograph pictures of the behaviour of the streamers which showed that the streamers hung very close to the body when the ring was fitted to the machine.

Finally Major Green said he was very glad to find that such unanimity of opinion existed in favour of the ring.

PROCEEDINGS

EIGHTH MEETING, SECOND HALF, 65TH SESSION

The Eighth Meeting of the Second Half of the 65th Session of the Society was held in the Lecture Hall of the Institute of Electrical Engineers on Monday evening, March 10th, 1930, when a lecture on "German Commercial Air Transport" was delivered by Major Martin Wronsky, General Manager of the German Luft Hansa A.G. The lecture was a joint meeting with the Institute of Transport.

The chair was taken for the first half by Sir Josiah Stamp, President of the Institute of Transport, and for the second half by Colonel the Master of Sempill, President of the Royal Aeronautical Society.

Sir JOSIAH STAMP: The Institute of Transport welcomed the presence of a visiting society, the Royal Aeronautical Society. They had had various joint meetings with other bodies, but had never previously soared so high as to meet their colleagues in the air. He hoped this meeting would be the precursor of many profitable discussions.

GERMAN COMMERCIAL AIR TRANSPORT

BY

MAJOR MARTIN WRONSKY

(GENERAL MANAGER OF THE GERMAN LUFT HANSA A.G.)

Paper presented at a Joint Meeting of the Royal Aeronautical Society and of the Institute of Transport in London on Monday, March 10th, 1930.

Introduction

Three years ago I had the pleasure of speaking before the Royal Aeronautical Society, and I feel highly honoured that I have again been requested to say a few words about the German commercial air services. From this request I draw the conclusion that Great Britain is as much as ever interested in the progress of German commercial flying. The essential basis of good relationship between the nations, namely, that in order to understand each other they must know each other, applies also to the realm of commercial aviation. The present developments in commercial flying demand that the nations interested shall work with one another and not against one another. This, however, will only be possible if there is a mutual understanding and knowledge of air activities on both sides.

If, in the following, I try to give a general review of the present developments and objects of German commercial flying, I will remember that I am speaking chiefly to those interested in commercial transport, and will consequently confine myself to outlining this side of our undertaking, and omit as far as possible all technical questions. Firstly, may I be permitted briefly to refer to a few facts, political and commercial, which have greatly influenced the development of German aviation? Germany, vanquished in the world war, was obliged under the Treaty of Versailles to refrain from any colonial activities and from any military flying. The consequences of the lost war caused great commercial

depression, combined with a catastrophic monetary inflation which dangerously undermined the political and commercial foundations of Germany.

In my opinion it is impossible to overlook these facts if one wishes to give a fair and critical picture of German aviation. Above all, the abandonment of colonial activities and the absence of military aviation have, from the beginning, placed our flying on a completely different basis to that of other European powers. For one thing there has been the lack of the invaluable technical pioneer of the commercial airplane, the older military machine with its advanced constructional design, which offers for man and machine the best experimental possibilities for the great duties of civil aviation; for another, there is also the lack of Colonial air ports, which most of the other powers possess in their overseas territories, and which automatically tend to direct their aerial activities in a certain direction. It is essential, therefore, in reviewing German civil aviation, not to lose sight of the complete absence of military and colonial flying activities. The aim of our total air transport became the foundation of a traffic organisation, which would combine the plane's usefulness with the already existing transport facilities, and thus open out new possibilities both for the development of transport and commerce.

Historical Review

Foundation Time

At the same time as in England, that is in the spring of 1919, Germany decided to explore the possibilities of the aeroplane for transport purposes, which, till then, had only been used as an instrument of war. Several comparatively short routes—about the distance of London to Manchester or London to Edinburgh—were utilised. These, however, left much to be desired both in the way of regularity and frequency. The initiative for the opening of such routes in those days lay exclusively with private enterprise, which was chiefly subsidised by the larger shipping firms, the banks, and the still remaining aircraft industry, which formed small transport companies. Their activities in many cases did not cover an area larger than Wales, and it was quite apparent that in consequence of their restricted spheres, they could not be a lasting success.

English Railways in the Years 1840—1870

One may well compare these beginnings with the early developments of the English railways, where also many small companies tried to introduce the then latest form of transport into a limited area, hoping for great commercial success. What happened in those days as a result of the lack of co-operation of the companies interested in the new form of transport, had likewise inevitably to occur in aviation, the very existence of which can only be justified if long distances can be bridged. Only the co-operation here, as there, brought progress.

Concentration Dualism

In the spring of 1923 the first steps were taken in German aviation which led to the creation of two large concerns. These two, which in their actual organisation were united, appeared outwardly to be in the strongest competition, thus hindering the combining of work and capital, and the possibilities of creating a united air organisation and traffic policy. After three years of competition, in which both concerns rendered valuable pioneer work, inside and outside German territory, an agreement was reached which resulted in a fusion into a single concern the German Luft Hansa A.G. Naturally, this important change greatly influenced the first ten years of the development of German aviation, and only through this amalgamation was a strong basis for a general air policy founded.

Duties and Form of German Luft Hansa

Now just a few words regarding the duties and the commercial construction of the German Luft Hansa. Just as Imperial Airways, Ltd., in Great Britain, the Luft Hansa in Germany is commissioned by the State to carry on the development of civil aviation. This recognition by the Government consolidates its position, but in nowise does it confer a monopoly, as actually any concern, although without State subsidy, is at liberty to enter into aviation in Germany. As compared with the Imperial Airways, in Germany the public are shareholders of the Luft Hansa. Whereas the British Government demands repayment of the subsidy out of any future profits, with us the subscriber, being a shareholder of the company, has therefore a right to participate in the direct profits; although for the present the subsidy is so finely calculated that no actual profits can be made. The Luft Hansa constitutes a limited company; the German Empire, the German states and towns, and all leading industrial, banking and traffic undertakings are shareholders. It does not therefore represent a purely Government concern, but belongs to the mixed industrial category. The State safeguards its influence by control rights and the passing of special decrees, which, however, to the public, are shown as of a purely private industrial character. It seems to me, at the present stage of development, to be the best constitutional form, in which, together with a certain amount of State sanction, far reaching possibilities are given to the activities of a private company which serves the whole country. Especially is this so in the administrative respect, where its character is emphasised as a pure transport undertaking, and for the development of transport, and independent of the aerial industry, which is designed for constructional purposes.

Working Formation

The German Luft Hansa is composed of the main or head administration, four divisional departments, of which each possesses its own head administration for a certain area, besides the local flight controls. Further, in the main transport centres outside Germany, such as London, Paris, Amsterdam, etc., it runs its own offices, which work in close conjunction with the local companies for the development of transport. Altogether the Luft Hansa last summer maintained its own service stations in over 100 large European places, of which about one-sixth were in foreign countries.

International German Traffic

Regional Companies

Special mention should be made of the co-operation of the Luft Hansa with the so-called regional German air companies. These are those undertakings which in the first few years of commercial air transport, under their own title, operated transport routes. Later, however, after the amalgamation, they agreed to give up their independence, and for a share participation, placed their aerodromes at the disposal of the Luft Hansa. Their main duty to-day is to further the aerial transport idea in their own district, and to interest the Government and the industry in the organisation and maintenance of certain inner German routes, and to obtain for these the necessary subsidies. Out of actual transport companies they have gradually developed into administrative departments. They give to the German air transport organisation its special character, for we miss in all other continental states similar arrangements. Their existence in Germany is explained by her being a Union of States, formed by the amalgamation of separate countries. These countries have maintained, on many points, their own former rights, as well as on the internal transport policy. When the German Luft Hansa as a monopoly air transport company was created, the

various States made their agreements on condition that certain guarantees be given by the Government for the development of the internal German air transport. As a company, sanctioned by the Government, the German Luft Hansa has also to fulfil in this respect far reaching transport obligations.

Advantages and Disadvantages of the Internal German Transport

In any case this condition of affairs, in many respects, has its good points. It is to be remembered that Germany may not maintain any military air activities. Thus the technical developments of the aeroplane and instrument industry were really only in the possession of the Luft Hansa. Thus every new line, if only of a distance of 100 km. offered an enlargement of the development field, giving possibilities for improvement to material, and experience to staff, and making it possible to revive the industry. It can be claimed that the German air industry and transport would not have reached its present position so quickly if the internal German air developments had not worked on these lines. Through the internal German air lines the technical development received, and still receives, means which otherwise would have been unobtainable, as these lines are mainly subsidised by the various states and towns. Furthermore, the internal German air system has made the German people " air minded," through it being possible to bring the air transport practically to the door of nearly every inhabitant, and the majority are in favour of the idea.

One must not overlook, in this connection, that the ground organisation received from this considerable advantages. Germany to-day has over 70 to 80 aerodromes and transport landing places, which have been created in the last ten years, and in the lay-out of which the most modern experience of aerodrome building and development technique was utilised. Although with the expansion of traffic, in which the increasing development to long distance transport predominates, several of these stations will fall out of the general transport plan, they will still possess high values for air taxi traffic, as collecting places for sport flying, and as air goods stations, etc. The development of the night transport, which I shall discuss later, is considerably helped by these places.

Collectively, I can therefore say that the internal German air transport in its total development has many advantages. In spite of this a certain reorganisation is taking place in which unprofitable routes and special short distance routes are to be abandoned by the Luft Hansa, whilst routes with heavy passenger and goods traffic, such as Hamburg-Munich or Frankfurt-Berlin, are to be developed by improvements to planes and service.

International Transport of the German Luft Hansa

The main duty of the Luft Hansa is naturally the linking up of Germany with the International European and world service of the future. Since its formation this aim has always been kept in view, and in foreign countries has received, in this, universal support. The Luft Hansa has built up its whole international transport policy on the idea of a commercial co-operation. It wants no supremacy, but considers the correct way is to work harmoniously with foreign air transport companies, to create a transport net serviceable for the whole European trade. I am pleased to ascertain here, that other countries have also this aim, which is confirmed by the International Air Transport Association, and without which the idea of a serviceable European air transport service could not have been carried out so quickly.

I would like to say, that, in my opinion, as regards air transport companies, the continent of Europe has reached saturation point. Undoubtedly there are countries who afford the luxury of their own air transport companies with their own air services, although, thanks to their excellent traffic position, they are included by alien companies in the general European air system. It must not be

forgotten that the working expenses to a large extent are met out of public funds, and that open competition will scarcely be possible in this part of the world in the next few years. Only the utmost concentration can assure progress, not only in the internal working, but also in the general European air transport. A thorough rationalisation would be preferable, and the idea of a combined air and transport political Europe would be near, although I admit, that it would be doomed to failure so long as every country must subsidise its air service so heavily, and so long as everybody considers commercial air transport as their own.

Later, when the financial success of air transport is assured, the companies of each country can compete. Absolute co-operation on international basis must remain as long as all companies live at the expense of the taxpayer. At least, the air companies of Europe in continuing their great aim, should combine in organising large outer European routes, and not work against each other. The technical difficulties are, in themselves, severe enough to prohibit open competition. Within the separate countries a universal company seems to me to be the best to-day. Undoubtedly it would possess more striking power, and would be more economical than a number of regional companies such as are to be found in France.

My interpretation may perhaps be contradictory to the conditions as they are found in Germany to-day, where next to the Luft Hansa, the North Bavarian Air Transport Company, Ltd., maintains regular air services. This small company looks however for its field mainly in the inner German routes, which could simply be called short distance flights, and receives support exclusively from local authorities.

I may mention that we have come to a friendly understanding to avoid competition, and more clearly to define working areas.

Germany's Transport Position Demands Special Energy

As regards the policy of the German air transport in Europe, I would again mention that our country does not possess any colonies, and thus certain aims of our traffic policy are not so obvious as in the case of Great Britain or France. For instance, one can see these two countries gradually extending their air routes towards colonies adjacent to Europe. This, however, is not the policy of the German air transport. Instead, the traffic requirements, owing to our position in the heart of the continent attracts our special attention. Rightly, Sir Sefton Brancker called Germany "The air cross of Europe." From this we get the directions for the policy of the German air transport. Our duty must be to create regular and safe express connections between Germany and all neighbouring States, between the centre and the periphery of Europe, for the furtherance of German trade. The route map of last summer shows that we have nearly fulfilled this aim, for, as already mentioned, the co-operation has proved itself.

With regard to the organisation of routes beyond Europe, the German air transport policy has been queried. It is said that countries possessing no colonies and mandates need not pursue air services beyond Europe. It is certain that no imperialistic ambitions govern us. World transport is a business, and is allied with world trade. World trade demands world transport! Therefore we do not want to confine ourselves to the borders of Europe, but wish to participate in world transport, even if only to those places of the globe commercially connected with Germany.

Again the following are our aims:—We want to connect Germany with the important industrial places of Europe by an organised traffic system. Beyond the confines of Europe we want to fly over a few of the main air routes to places in which we are industrially interested. This co-operation we consider better

than the attempt of securing monopoly support points to keep away other nations from the main air routes. This must be emphasised with the Imperial Airways, Ltd., as we have always found every sympathy for this co-operation.

We are chiefly confining ourselves in establishing a connection between Germany and those countries, both in Europe and outside, which are already highly developed industrially. Another important future duty for the aeroplane is to bring express services to those districts hitherto undeveloped by transport; in other words, to replace the camel caravans by the aeroplane, or at least to assist them. In such places of the world, activities on the part of a company, subsidised by German ratepayers, could only be justified by industrial openings in the interest of Germany, which would only be the case if colonial or mandate countries came into consideration.

According to the contour of Germany, we wish to organise branch services to our great aerial routes, concentrating on our far distant ones. In the choice of these routes the industrial requirements are to be decisive.

We wish to supplement the planned service by taxi and tramp flights, making a valuable addition to the planned service.

We are driven to these plans, not from a military point of view, but through commercial and traffic political requirements. Having only 150 pilots and 150 aeroplanes, military aims are impossible, for they would only result in military play. This would be degrading to a large country.

Subsidy

After this political transport review, allow me to mention now the commercial problems. Subsidy and financial success! The first question here also is, on what conditions altogether are subsidies given by governments? Generally only for the fulfilling of a public duty, which can either be of an educational or an industrial character. In nearly all civilised countries of the world, public schools, universities, high schools, museums, etc., for instance, and in some cases even the opera houses receive financial support from public funds, so that practically every visitor to these institutions is subsidised. In all these cases it is a solution to solving educational duties. As transport and industry are inseparable, the maintenance and support of every kind of transport service therefore becomes a political industrial duty. For instance, in Germany the building of roads costs yearly hundreds of millions of marks, of which only a fraction is received back in the shape of motor car duties. Subsidised undertakings are also extended to canals, nearly all the steamship companies of the world, the railway passenger services in some countries, and the maintenance of many local lines, etc. In one large German town, for example, the underground railway has to receive a regular advance of nearly four marks per passenger. One pays and rightly pays, because the supported traffic organisation fulfil a public duty, although they may not be a paying proposition.

The transport aeroplane must therefore prove that it is fulfilling a public duty, then it has a claim to be subsidised, especially in view of its short existence in comparison with the older and great traffic systems.

In going closer into the question of subsidy for the air transport, I would like first to examine a few characteristics of the German and English systems. Here, as there, the subsidy is based on the flight capacity. In England it is paid in proportion to the h.p. miles flown, whereas in Germany the mileage basis, which varies according to the size and type of plane, acts as the basis for calculation. We are now endeavouring to get the subsidy on the basis of a uniform ton-mileage basis. We promise ourselves a simpler way of settlement. The differentiations created by the varying types disappear and allow a clearer cost and success calculation, which we table for each individual route separately.

I would like to emphasise the fact that Imperial Airways, Ltd., is in a more favourable position than we are, by having a subsidy guarantee contract with the Government for many years, this alone allowing a far-seeing transport, renewal and staff policy. Up to the spring of 1929, the air transport permit and also the obtainable subsidy amount was fixed annually in Germany, thus creating a highly disadvantageous uncertainty in the working element. Only in 1929 the Government promised the German Luft Hansa a certain subsidy for a period of three years.

Another point should be mentioned. Whereas in England, and most other countries, the Governments act as sole financial supporters, in Germany the conditions are more complicated. For not only the Government but also the various States, and even the towns, give considerable amounts to the Luft Hansa for the expansion of the inner German air transport. The foreign transport, however, is solely subsidised by the Government.

Subsidy Comparison

A comparison of the air budgets of the various European countries is interesting. In 1929, they were:—

Germany	... ...	1,037,000	pounds sterling.
France	... ...	14,300,000	,, ,,
England	... ...	16,200,000	,, ,,

Calculated per head per population, and taking into consideration the total expenses of the air service, including all charges for ground organisation, experiments, etc., the cost to the German nation per person is one shilling per annum; in France and England, owing to the additional expenses of the military air service, it is increased to several shillings per person. The actual amounts allowed by the Governments for air traffic are, in round figures:—

England	... ...	350,000	pounds sterling.
France	... ...	1,400,000	,, ,,
Germany	... ...	800,000	,, ,,

Although the subsidy for the civilian air service represents a nominal fraction of the total budget, in spite of the previously mentioned justification for a subsidy, it should remain the most important duty of all aerial transport undertakings to reduce by all means the amount of the support, and gradually to reach complete solvency in all their organisations. We find everywhere to-day—with a few exceptions in South America—a disproportion between expenses and receipts. The subsidy is given to equalise this.

Financial success depends upon expenses and receipts, the latter being governed by the tariff charges. The conditions existing to-day do not allow an increase in passenger or freight traffic charges, excepting in certain cases. Everywhere, increased tariff rates have resulted in general traffic reductions, which must be avoided in such pioneer undertakings. There are even no logical reasons why the customer should be called upon to pay increased rates. One must admit that the aeroplane has not yet fulfilled all requirements as a transport service. Admittedly the aeroplane is speedy, but during the last few years no increase in speed has taken place. Although the reliability, which I shall mention later, compares favourably with other transport services, the punctuality of the organised European services is between 95 per cent. and 97 per cent. The aeroplane lacks the comfort to which the travelling public is accustomed in express trains, motor cars and express steamers, and which should be found also in long distance aeroplanes. This question should not be treated negligently. The air passenger wishes a certain amount of comfort; he wants to read, write, smoke and converse, and on a long flight wants his freedom. It should therefore be the main duty of all aeroplane constructors to attend to these wishes as well as the elementary ones of safety, speed, etc.

Furthermore, it must not be forgotten that in the autumn and winter months services are unpunctual, and it frequently happens during the rush season that the demand for seats exceeds the supply, resulting in passengers returning to other forms of transport. It can be understood, therefore, that the aeroplane appears to the modern traveller unreliable and frequently unavailable. We have, therefore, not yet attained perfection, and undoubtedly, insufficient progress has been made in recent years.

Not only in Germany, but in a few other European countries, it has been noticed that practically no advance in passenger traffic has taken place during the last year, and in some cases there has been a decrease. In Germany's case, an advertising campaign was started too late last year, and therefore suffered in effect, which was due to the amount of the subsidy from the Government only being made known shortly before the main traffic season. It is probable that this is not the only reason for the insufficient support of the aeroplane service. Certainly, in some cases, the passenger, although quite favourably disposed to air travel is disappointed with the absence of comfort, and also by the unpunctuality. Also not alone the general trade depression, but several accidents, during the last few years, in all countries, having been sensationally reported in the newspapers, have had detrimental effects.

And what applies to passenger traffic also applies, to an extent, to post and cargo traffic. Without doubt the freight customer would be prepared to consign larger quantities by air routes and pay higher rates, if safety, punctuality, speed and constancy could be guaranteed, thus making it easier for him to give up the other transport systems. The revival of the frequence, which shows us the confidence of the public in our young undertaking, depends entirely upon the development in the motor, battery and instrument industry. Without these, in my opinion, it will be very difficult to show increases in the undertaking, with the exception of the postal service to which I will refer later. Industry and transport should, by constant service, preparedness, and a large margin of safety in aeroplanes, leave nothing untried to assure good sequence, otherwise the demands on public funds would be unjustified at least for the European traffic.

The technical element also rules the expense side. Neither the best organisation nor the most rational control can reduce expenses, if the aeroplane constantly shows such a great disproportion between total weight and serviceable weight, as is found to-day in all types, and to which must be added the high producing and maintenance costs of the batteries and motors. Even to-day mass production of modern traffic aeroplanes in Europe is impossible because a type has not been standardised and the justification has not yet arisen in any country.

Although it may not be possible in this address to give detailed amounts for the expenditure on aerial traffic, a few examples, however, will show the reasons for the extraordinary high working cost in the civil air transport.

Firstly, the previously mentioned high production cost for aeroplanes and motors plays a large part. A ten-seater, triple engined transport aeroplane costs roughly RM 200,000; an all metal even RM 300,000 or more. In an aerial transport undertaking about 85 per cent. of the purchasing capital alone is required for aeroplanes, which makes the influence of the high purchasing costs apparent.

The proportion of fixed to liquid expenses is about 55 per cent. to 45 per cent. Inside the fixed expenses which cover depreciation, insurance and fixed administrative expenses, depreciation and obsolescence are the first which appear immediately as being specially high. Of the fixed expenses, depreciation and obsolescence represent approximately 50 per cent., and of the total expenses about 25 per cent. If it were possible to increase the life of the aeroplane and the motor, which is roughly five years and four years, respectively, it would result in a considerable reduction in the fixed expenses.

Insurance also forms a heavy charge on air transport. Including the "Kasko," accident and third party risk, they amount to roughly 10 per cent. of the total expenses. Here, also, with continued safety, an improvement must be looked for.

In this connection I would mention that last year we introduced, as an experiment, an insurance system of our own for aeroplane and motors, which so far has been very satisfactory. Whether we intend to continue this system permanently, is questionable.

The administrative charges are only 6 per cent. of the total fixed expenses. A large part of this amount is used by the aerial companies in solving many development questions of a technical and political traffic nature, for which receipts can only be expected in the distant future.

Of the liquid expenses, the main item is the amount required for the preparation and maintenance of the aeroplanes and motors. Of the total they represent about 22 per cent. Only by considerable technical progress will it be possible to reduce the amount required for preparation and maintenance. In any case progress is noticeable here, as the Luft Hansa has, as an experiment, increased the working hours of the motors, between two overhauls, thereby showing a saving under this heading of 25 per cent. In the aeroplane batteries, too, an improvement is noticeable, although the savings here, so far, are not so large, owing to the frequent necessity of special examinations.

Mention also should be made of the heavy expenses of the ground organisation, because the large staff and material of an aerodrome are often insufficiently utilised. Frequently the traffic in an aerodrome is confined to a few hours, during which large numbers of aeroplanes arrive and depart, therefore requiring a large staff organisation which is without occupation at other hours of the day. The expenses on the ground organisation are increased, if the traffic in the winter months is reduced, or even cancelled entirely, as frequently happens with many air transport companies of Europe. This explains that with a few air transport companies, especially the Imperial Airways and the Koninklijke Luchtvaart Maatschappij, the balancing of the working expenses out of income is already possible up to 50 per cent. These companies maintain a very concentrated air traffic net, with few aerodromes. The Luft Hansa, whose route net is larger and more extensive, maintains more aerodromes in proportion. The balancing here of expenses out of income has not yet reached 40 per cent.

In connection with the effect of the traffic net on the working cost, I would like to touch upon the examination of serviceable organisation and working activities, which Professor Pirath, the head of the Industrial Institute in Stuttgart, has made. Pirath's conclusions are that the value of the aeroplane for transport for regular traffic appears disadvantageous if it is only to work routes of at least 500 km. Short distances should only be used spasmodically. The best justifications for the air traffic, in his opinion, are only when the distance to be flown exceeds 1,000 km. He then arrives at three traffic stages; namely, up to 500 km. spasmodic traffic, 500 to 1,000 km. national and international local traffic, over 1,000 km. international and intercontinental traffic. The third, the longest stage, is easily the most profitable, as due to the transport speed it is without competition from all other traffic, and therefore gives the best opportunity for obtaining higher tariff charges. The second stage could also have favourable results if route management, aeroplane arrangement and traffic volume, etc., were well fitted into the requirements of the international traffic. The most unfavourable stage is the first (1 to 500 km.), the railways and the motor car, especially the sleeping car, being dangerous competitors, and the inclination to use the aeroplane is lessened, owing to these traffics being so well organised. I would like to mention that Pirath, in his examinations, has naturally reckoned only with the travelling speed as found in the air traffic today. Under these conditions one must throughout agree with his conclusions,

although there are exceptional cases, like the London-Paris route, which according to Pirath would fall into the first stage, but which has shown extremely satisfactory results, due specially to favourable traffic conditions.

It is certain, that for the financial result of an aerial transport company, the formation of the aerial net plays an important part. The ruling factors are the following:—

Is the net comprised of short or long routes?

Has it few or many intermediate landings?

Are there single or many daily services on the individual routes?

Is the net confined and concentrated to one home aerodrome, or is it extensively expanded?

Is the flight plan so arranged to guarantee, for instance, that an aeroplane can cover the single and return journey of a route in a day?

Does the flight plan satisfy the trade requirements, taking into consideration the various conditions appertaining to passenger, postal and freight services?

Does the service work the whole year round, or only part, resulting in staff and in material not being required in the slack season?

Although these points do not affect the financial result so much as high producing expenses and maintenance charges for aeroplane and motor, they are still of considerable importance.

Many of these conclusions are thoroughly examined in Professor Pirath's latest work "Forschungsergebnisse" (Examination Results), 2nd edition, whereby the intermediate landings in the continental aerial traffic net, commercially speaking, should not occur more frequently than every 300 km. and then only in towns of 300,000 inhabitants and over, as otherwise the regular expenses of the route would increase considerably, *i.e.*, the takings would appear unfavourable. Germany, having such a large number of well populated towns and with heavy interest in the air traffic, such an ideal system, especially in our country, can only be realised gradually. Where several large towns are close to each other, Pirath suggests creating a central aerodrome, serving all these towns. As an example, compared with the West German industrial district, England can show over five large industrial areas dependent one upon the other, which suggests that very little practical value would result from having here an inter-town aerial service in view of the excellence of the English railways. In fact, London could be considered as the central aerodrome for England and Scotland, from the point of view of continental traffic.

Another conclusion of Pirath, namely, the reductions of the current expenses by increasing the service of a route we have already carried out, as on many of our main routes dual services are flown daily, and partly by giving the second service an alternative route.

Judging from our experiences of later years we only intend to maintain our inner German system in so far as it brings actual advantages to the industry, which means a satisfactory regularity.

Pirath's idea of a combined working of the traffic undertakings we have to a large extent carried out by an agreement with the German State Railways, whereby every aerial passenger, if he could not start his aerial journey, or had to break same *en route*, is entitled to continue to his destination by express train (1st class), without additional charges.

Going more fully into the various classes of traffic, it has already been mentioned that the passenger traffic in 1929 showed a reduction compared with 1928 from 110,000 to 87,000 in passengers carried, representing a reduction of 21 per cent., but one must remember that the km. capacity of the company in 1929 compared with 1928 was reduced by 14 per cent.

The postal and freight traffic, during the last year, showed considerable increases. We arranged in the spring of 1928 special rate tables from Berlin to London, and to Paris, with satisfactory results. The German post, last year,

also temporarily arranged aerial postal routes from Berlin to London, Copenhagen and Stockholm, and contracted with the Luft Hansa for the whole working arrangements. For their short existence, these routes, which also handle freight consignments, claim a remarkable success. Compared with 1928 the total weight consigned by these special freight routes has increased from 122,000 to 277,000 k.g., and that of the post from 56,000 to 104,000 k.g. Expressed in percentages this means 126 per cent. increase in freight, and 86 per cent. increase in postal traffic. These routes are, therefore, to be further extended.

As a matter of interest the German postal authorities did not pay on a km. basis, but after the American principle, on the weight dispatched. This is not a subsidy, the payments being far more for services fixed at a minimum amount, and thereby resembling an extra guarantee.

Just a few words here on the subsidy conditions in America. Continually in the European daily and trade Press the ideal conditions existing in the U.S.A. are brought to the notice of the air companies. No subsidy, but still solvency! This secret should be examined. First all foreign routes of the U.S.A., for instance, Canada, Mexico, etc., receive a subsidy on the same basis as in Europe, that is on the distance flown, the only difference being that it is considerably larger. On the internal routes payment is made on the quantity of postal packages handled. This payment is very large, larger than the postal surcharges for air post justify. Frequently, also, the ordinary post is included, namely, that for which no surcharge has been paid by the consignees. Thus here also a regular subsidy system exists, and rightly so, for the air post in the U.S.A. is working excellently and gives invaluable service to industry.

Next to the special postal routes the German Luft Hansa worked its own freight routes to Paris, to the Rhein-Ruhr district, etc., these being well patronised. The freight service has worked in conjunction with the German railways efficiently; the latter taking over the handling and despatching of parcels from such places and on such railway routes as are untouched by the Luft Hansa. Every small German town is automatically linked to the aerial net, and every industrial concern has at its disposal the advantages of a speedy aerial service from the nearest aerodrome. For example, in 1929 the German railways handled aerial consignments from 287 places. As in our own service we only touch about 70 aerodromes, at least 210 of these places must be without aerodromes; theoretically therefore the traffic value of our service to the whole industry has been more than doubled. It is interesting to note that 90 per cent. of all consignments by railway and aeroplane were for export, and of these 90 per cent. emanated from places without aerodromes. As the co-operation between railways and aeroplanes has proved advantageous for the goods traffic, it should become available to the industry of other European countries by a general adoption. This seems to me all the more necessary, as the international adoption of aeroplane-railway-passenger traffic has already been agreed upon.

I would like to emphasise the fact that no increase in the frequence of the goods and postal traffic could have been made if we had not made preparations for the separation of passenger and goods traffic. This especially refers to the flight plan. The passenger traffic flies to a fixed schedule during the day, postal and freight have different schedules. The increase in the freight traffic would hardly have been possible without the extension of the night routes from Berlin to the west. Past experience has shown us that even the most favourable routes have very little postal traffic during the day. The newspaper postal service is an exception. This refers to some of the leading papers, whose lunch and afternoon editions have been forwarded in large quantities on some of the inner German routes. Also the parcel traffic inside Central Europe will not increase so long as night services cannot be utilised. That actually in large circles of the industry the new traffic system is necessary is shown by the results of our postal

and goods routes; for as soon as the time of departure was mainly transferred from day to night, the increase began. This refers chiefly to the inter-State service and also to the inner German long distance service. Without a doubt, the present freight routes only carry a part of the available traffic, and the creation of further routes to other industrial centres of Europe seems to me to be only a question of time, or rather of obtaining the necessary capital for the extension of the night service. It is certain that the extension of the night service and the postal and goods traffic are closely connected with one another. We therefore strongly support the extension of the night service, and at first chiefly the Berlin-London and the Berlin-Paris routes. When the chain of beacon lights has been completed, which we anticipate will be shortly, we hope, in conjunction with our English and French traffic friends to take up the postal goods exchange between London and Berlin, and Paris and Berlin, during the hours of 11 p.m. and 6 a.m. With this night postal traffic, solvency in the so-called second stage, *i.e.*, a distance up to about a 1,000 km. can readily occur. If by a regular service, letters are taken in one night from Berlin to London or Paris the public would be prepared to pay extra charges for such a speedy delivery. This would nearly cover the working expenses, requiring little subsidy support; although I would not like to query the moral obligation of the postal authorities of Europe to utilise such an express service for their total mail without any postal surcharge! Shortly we anticipate organising a night service to Southern Europe. To the East, in the direction of Moscow, the night service has already been working successfully for two years. In 1928 our machines travelled on night routes over a quarter of a million km. The regularity in the summer months was nearly 97 per cent., being only about ½ per cent. below that of the total traffic.

In this connection allow me to say a few words on the question of safety. It is certain that accidents will occur in every kind of traffic. These accidents, however, in the air service are taken by the public too seriously. More so than evidently was the case during the first development years of other traffic means. In a report of *The Times* we notice that, in the year 1841, after ten years of existence, 22 passengers were killed and 30 hurt in the English railways. The yearly working capacity of the railways was then about 3½ million km. Compared with this, in the tenth working year of the German civil aerial service, with an annual capacity of about 10 million km., six passengers were killed and nine hurt, which means with three times the capacity and five times the speed, the number of killed is reduced by three. Another comparison:—In Berlin, in the year 1929, altogether about 27,000 traffic accidents took place, which means about 75 per day, or one every twenty minutes, in which roughly 500 persons were killed and about 11,000 hurt. In London these figures are about the same. And in spite of that, the English railways in 1841 did not cancel their services. Also in Berlin the streets are used constantly without fear of accidents. I believe that if the public is not influenced by sensational reports of aerial accidents—mainly due to sport and military flying—but takes notice of the large number of accidents on other transport systems to which it is accustomed, and lastly sees how the number in the aerial traffic shows a constant reduction, it must be admitted that it would be wrong to avoid the transport aeroplane for fear of accidents.

In the German Luft Hansa, from 1926 to 1928, the number of breakdowns, based on one million flight km., dropped from 19.6 to 12.7. The total breakdowns between 1928 and 1929 have been reduced by 46 per cent. and the number of passengers hurt by 70 per cent. The proportion of casualties in 1926 was 1 to 436,000 km. flown, in 1929 only 1 to 1,498,000 km.

How can safety be increased still further? The accidents have in nearly all cases either been due to defects of the working element, the motor, or to weather

conditions. As regards the working safety of the aerial motor, it must be borne in mind that as recently as twenty years ago the automobile motor represented a highly unreliable power unit, and long journeys were more or less impossible on account of the frequent breakdowns. To-day the automobile motor is perfect throughout, therefore the time of an equally efficient aerial motor cannot be too far distant.

More difficult to overcome are the weather conditions, in other words, the fog. To help here, experienced members of our staff are constantly working to find new instruments to increase safety, and on the perfection of the dashboard instruments of our aeroplanes. During the winter months—the slack season—extensive educational courses are arranged for the flying staff. For instance, at present a large proportion of our pilots are taught "blind flying." This demands thorough knowledge of the meteorological and wireless range and route finders. The pilots of our seaplanes have lectures to prepare them for the examination in the "Great Flight," thus giving the staff experience in long distance land and sea service. By adopting the gyroscope and the directional wireless, night flying and flying in fog have become much safer, giving better conditions for the regularity of the winter air service. Although there is no comparison in the winter traffic with that of the months April to September, I would like to make it known that in Germany, compared with other years, we have achieved considerable encouraging working results. Thanks to taking up the night route Berlin-Hanover, the service with the West European centres can be maintained in the darkest months. All the before mentioned improvements have considerably assisted in increasing the regularity.

After this short discourse on safety, allow me to return to the before mentioned co-ordination of the Luft Hansa and the German railways. It would prove specially useful during the winter months, as the unavoidable shortening of the flight routes during the short days would be equalised by favourable railway connections. The transit times of consignments are scarcely affected. Also in cases where no night service exists, the night train has been included with great effect in the transport system. Thus the post destined for Spain runs by night express from Berlin to Stuttgart, the Balkan post to Gleiwitz, and early in the morning is taken over by aeroplane. I believe that this co-ordinated railway-aeroplane service will become very serviceable in the next few years with the development of the long distance traffic.

And what applies to the railway also applies to steamers, and even the motor car. Valuable traffic advantages can be created by useful co-operation of liner and aeroplane, which is all the more important where the actual ocean aerial traffic has not yet been carried into effect. We have thus arranged with the North German Lloyd an aeroplane delivery service by which European travellers, immediately on arrival at a German port, continue their journey by special aeroplane to the inner parts of the country—an arrangement which has been favourably received, and which is valuable as an advertising medium for further aerial journeys. In the postal traffic, the co-operation with steamer is intensified, as the express post is released from the deck of the steamer by means of catapult aeroplane a few 100 km. before reaching the European mainland, and is taken direct to the traffic centres. We have been successful so far in reducing the travelling time of the post between New York and Berlin by about 30 to 36 hours. This will be doubled through the night service, as urgent and valuable oversea postal communications are sent to the steamer by special plane a good time after the departure of the boat from the German port. The aeroplane overtakes the steamer 100 km. west of Europe, is taken together with its consignment on board, starting again with the same consignment an equal distance from the American coast. In the North American traffic, for the time being, we intend to maintain this form of co-operation. For increasing the

speed of the overseas traffic to South America in conjunction with Spain—and with France we hope—we intend to direct our aeroplanes via Marseilles-Seville to the Canary Islands, to deliver the post there, and to collect as well. In both cases we have reached the first step towards an Atlantic air service, which later on will be carried out by aeroplane entirely. To this problem also our full attention is being given, and we assume that—as far as aeroplanes are to carry the traffic over the ocean areas—this can only be done by capable ocean flying boats. As our first motive, we place the extension of the aerial post and goods traffic, as without doubt very shortly the aerial post will give the biggest opportunities for solvency of the inter-continental traffic. Under present conditions, and those of the near future, one should not be too optimistic about the possibilities of trans-oceanic passenger traffic. The comfort in the aeroplane, even in five or ten years' time, due to the limited space, will not compare with the luxurious arrangements of our ocean giants—a question which is more important with ocean journeys than with land, and will draw the wealthy travelling public first to the steamer. To me, therefore, it seems more important to give attention to the building of capable freight and postal aeroplanes for the trans-Atlantic traffic, and then to work for the passenger traffic. If we consider that 80 per cent. of the total world trade crosses the Atlantic Ocean, I believe that my arguments cannot be ignored. In Germany alone and its neighbouring States (Central Europe), the daily despatches of the letter post for North America amounts to about 2,300 kg., for South America to about 500 kg., and for East Asia (Japan and China), 200 kg. In one year between Europe and Asia about 800 tons of letter post were forwarded (according to Pirath). Add to this the very heavy freight service to these world centres, the solvency, due to such quantities, would be much easier than the passenger traffic, even if only one-third is carried by the air service. To accomplish this as already mentioned, an absolutely reliable, capable, and fast freight aeroplane, which we do not possess to-day anywhere, is necessary.

We also believe in the utility of the airship here, and we hope to work together with the Zeppelin Airship works during the coming year in opening the great aerial route to South America. In this co-ordination the large aeroplane would probably work from Central Europe to a port in South Spain; there the airship, whose wonderful feat has been acknowledged by the whole world, would receive the consignment, deliver same to the North East coast of South America, and hand over to the seaplanes of the Condor Syndicate which is allied to us. Furthermore, we contemplate a postal aerial service to the Far East. Several experimental flights, carried out by us to Peking and Irak, have proved that the problem of working technical points is solved. The difficulties here are more of a political character, as the aerial route crosses German, Russian and Chinese territories. In any case, I may say, that the realisation of these two world traffic aims can only be achieved in a serviceable co-ordination with the older traffic means, and an objective co-operation of all interested Governments and traffic companies in the materialisation of these plans.

The aeroplane has already proved that, included in the general traffic arrangements, it can fulfil a high educational mission in the service of the international traffic and goods exchange. It is in our power to guide this young transport service to increase progress and to the opening of new traffic areas. Then it will not be " The Great Delusion " as an English writer called it, but a valuable addition to the other transport services, and so fulfil its great industrial and educational objective. To achieve this aim should be the main duty of all nations.

Discussion

Sir Josiah Stamp: Herr Wronsky, at the outset of his lecture, had apologised for his lack of facility in the English language. Such an apology was quite unnecessary. This paper might easily have been read by an inhabitant of these islands and have been more difficult to follow. He congratulated Herr Wronsky on the high degree of safety that his flights in the English language had achieved; his percentage of casualties was even smaller than that of his own air service.

Colonel The Master of Sempill: He rose mainly to express to the lecturer, on behalf of the Royal Aeronautical Society, their great appreciation of an exceedingly interesting and informing lecture. Many of those present would remember the paper which Major Wronsky read to the Society some years ago, and the progress which had been made in the meantime was certainly remarkable. He wished also to thank Sir Josiah Stamp for the remarks he had made at the beginning as to the value of the combined meeting of the two bodies. The meeting had given to the members of the Royal Aeronautical Society the greatest possible satisfaction, and he hoped it would be followed by other combined meetings in the future, especially under Sir Josiah Stamp's distinguished presidency. He was frankly ashamed when he heard Major Wronsky apologise for his English, for he himself was really unable even to thank him intelligibly in German. That he should have given so much time to the preparation of this paper, and have come over to this country to deliver it, was a compliment to both societies, which it was difficult to acknowledge in words or to repay.

Major Wronsky had thrown himself whole-heartedly into air transport problems in 1919, and he was responsible more than any other single individual for visualising the advantages to be gained by forming the national air traffic combine in which he, incidentally, was the pivotal man. He not only conceived the idea, but he was also instrumental in carrying it into effect.

The Master of Sempill said he did not propose to ask Major Wronsky a large number of questions concerning subsidies, and political matters of that kind, because he imagined these would be dealt with by the Director of Civil Aviation. There were, however, a few questions he would like to put to him. How many miles in his services were now actually flown by night, and how many night miles would be flown during the forthcoming summer season when the projected extensions were in operation? Was night flying going to be practised by flying boats operating on some of these routes as well as by aeroplanes? What flying boat routes, in addition to those towards South America, would be in operation. He had been pleased to hear Major Wronsky pay a tribute to the value and in fact the necessity of the ocean-going type of flying boat. Could he say something about the flying boats which had recently been developed in Germany, and to what extent they were to be used on these services? Then as to the type of engine employed, was there a growing tendency to use air-cooled engines in Germany in place of the water-cooled engines? To what extent was air taxi work or joy-riding carried on by companies other than the Luft Hansa? Major Wronsky had referred to the extension of the running time of engines between top overhaul and complete overhaul. What were the hours of running? Were engines to any extent being run on fuel produced from German coal?

The Master of Sempill thought that in face of the enormous difficulties that had been encountered in Germany, they must all be struck by the remarkable results achieved. A great service had been built up extending gradually over the world. During the last ten years in Germany alone they had created something like 70 or 80 air ports or air parks. They had an educated public who were anxious to foster air transport and thoroughly believed in it, and they had a scheme of co-operation, not only as between the heavier than air and lighter than air side, but as between air transport and the other older means of transport.

He thoroughly endorsed Major Wronsky's statement that they should work together and not against one another. Major Wronsky had said at the commencement that he had had little opportunity for practising his English. Well, he (the Master of Sempill) was sure his English colleagues would consider it a privilege to give him frequent opportunities for practising his English in their midst. He had the greatest possible pleasure in proposing a cordial vote of thanks to Major Wronsky for all that he had achieved in the organisation and operation of air transport and for the interesting lecture to which they had just listened.

Sir SEFTON BRANCKER: It was a great pleasure to welcome Herr Wronsky and to support the vote of thanks. Both the distinguished visitor and himself had been in air transport since it started. He thought that Herr Wronsky could claim to be the most experienced man in the world so far as air transport was concerned. His organisation had beaten all records in Europe, and was only outstripped by the United States, even in the United States no one single company had done as much. Air transport was an international question, particularly in Europe, and it was necessary that the people administering it should get together and work out schemes of co-operation, as was done amongst the European railways. He thought that Herr Wronsky agreed with the British policy of " the freedom of the Air." This policy implied, roughly, that every nation was responsible for the development of the ground organisation of air routes across its territory, and when such air routes were organised every nation had the right to fly along those routes as frequently and in whatever manner desired so long as they obeyed the laws of the nation concerned. That was the way to make air transport a commercial success.

The author had stated that the British Government was demanding the repayment of the subsidy. That was the case in the original contract, but it had been altered, in the latest contract the British Government had taken a block of ordinary shares in Imperial Airways, and had therefore become shareholders and would share in the profits, so that the demand for a return of the subsidy would no longer be made as in the past. The author had further stated that the German Government were arranging a ton mileage basis for the application of the subsidy which would cover the operations. No matter how the subsidy was applied it was bound to hit one back again somewhere. Originally in this country it was applied on the horse-power mile basis, because it was felt that the ton mileage could look after itself, it would be in the interests of the operating company to obtain as large a load capacity and paying load as possible, whilst the horse-power mile subsidy encouraged the use of more powerful engines and higher speeds.

It had been interesting to see the amounts received from the various German States and even from the cities for the development of the air service. He wished England would wake up and try and do likewise. If some of the English counties and big cities could contribute internal services they would soon get air transport inside the country as well as outside going very strongly; all the money obtained from the central Government at present was required for Imperial communications, and it was up to the local authorities to provide what was required for local services.

Herr Wronsky had spoken of the passenger traffic as slowing down and in fact decreasing. That sounded a little depressing, but the speaker thought the fact had to be faced that air transport needed to give sufficiently reliable service if the passenger was willing to pay more for the privilege of going by air. He had also rather suggested that no progress had been made in speed. The speaker was a strong advocate of going faster. It not only saved time, but it enabled one to fight head winds and so avoid unpunctuality and failure to reach the destination. He believed also in the necessity of frequency in air services,

a thing which, for long distances, was just as valuable very often as increased speed. He felt that these two factors, speed and frequency, were more important than the making of bigger and bigger aircraft. Big aircraft were wanted for operation over the sea, but so far as the land went he felt that the limit of size had been reached for the present, and that attention ought to be concentrated on speed and on the further development of a fleet using moderate-sized aircraft. This would again increase the demand of passengers, because when a reliable and frequent service could be given the public was prepared to pay for it.

There were many interesting figures given in the paper. When the author spoke about the age of an aeroplane as being only five years, the speaker recalled seeing only recently an aeroplane of the Luft Hansa service which he thought held the record of age. This was D1, Junkers Type 13, the first really commercial European machine, built in July, 1919. It had covered 800,000 miles, had been overhauled several times, looked as fresh as ever, and was still going strong.

He was in absolute agreement with what the author had said regarding distances. The longer the distance the better. One outstanding feature was the necessity that the flight should be under one control from end to end. An endeavour was now being made to obtain unified control from London to Australia.

Herr Wronsky had mentioned London as being the central aerodrome for England. With this the speaker did not agree. London should be the base for Imperial communication, but for European traffic a central aerodrome was bound to take its position somewhere in the North. The bulk of the traffic would be carried between the industrial North of England—Lancashire and Yorkshire—and the northern part of Europe. Therefore a direct link between, say, Hull and Hamburg would be of immense value, and this would necessitate the central aerodrome for England being in the North, London remaining, as he had said, the base for Imperial communications.

He wished to congratulate the author on the development of his night service. It was obvious from the start that air transport in Europe could never come into its own until operation took place by night, and Germany had done great pioneer work in this respect. He hoped it might be possible for us to take some part in the development of the night service between London and Berlin, which should be a great success.

In conclusion, he expressed the thanks of the two societies for the paper, which was of great value to them all, also for the assistance and sympathy of the author in the work done in this country. He was heartily to be congratulated on his success in face of considerable difficulties. The speaker himself had done a great deal of travelling on the service of the Luft Hansa. He always had the greatest confidence in its machines and pilots, and he hoped that those interested in air service in the two countries would go on for many years to come, helping the good cause of aerial transport and furthering by that means a mutual understanding amongst the different nations all over the world.

Mr. F. Handley Page: He could not quite understand at first why Herr Wronsky referred to the non-existence of the German colonies as a reason why Germany could not develop air transport abroad. That lack of colonies had not led to any lack of steamship development, and the example of the steamship had been a good one for making the Luft Hansa build bigger aircraft and fly all over the world. It seemed to the speaker that in air transport one looked at the thing far too much from the point of view of Government support and Government subsidy. He believed that subsidies were a great nuisance and ought to be got out of the way, but at the present time if one did put them out of the way, one would put out of the way also most of the air transport concerns. In its present form, however, the subsidy was very one-sided. It was given for

the operation of aircraft, to make up the inevitable difference between the receipts and the running expenses, and not the same amount of attention was given to the development of aircraft and aircraft engines for commercial purposes. The problem of running air lines would solve itself if the aeroplane could be operated at a price that would give a handsome profit to the operating company. He submitted that the greatest need to-day was for a subsidy or for money to be spent on the development of the engine, and the aircraft, so that the unit altogether would become more economically possible to run. When that came about he thought that the passenger would also obtain the greater comfort and freedom in travelling to which the author had referred.

He was sorry to learn that there were misprints in the paper, and particularly that the figure given for the British subsidy was an error. When he saw the figure as set out in the first proof of the paper, namely, £1,350,000, he hoped that it was an example of intelligent anticipation, because one generally found that people abroad knew more about what was to happen in this country than its own citizens. He hoped that it was an intelligent forecast of what the British Government was going to do this year for civil aviation, but he feared that he was far too optimistic in that respect.

Like the Director of Civil Aviation, who had just sat down, he wanted to congratulate Herr Wronsky on the success he had had in night flying. The whole success of the operation side of aircraft transport was very largely bound up with this question of night flying. It was useless trying to maintain a postal service between here and the business centres on the Continent if the letters had to be posted in the early morning for delivery late that same evening or the morning following; the air in that event would always be beaten by the railway train. What he would like to see was much greater development between this country and some of the centres abroad in regard to night flying which would expedite the post.

It was usual, he believed, for those who took part in a discussion to ask questions of the lecturer, but in this instance the lecturer himself had asked one question which the speaker felt that he could almost answer. He had asked how to obtain greater safety in aircraft. Perhaps it would be better if he (the speaker) indicated privately to the author afterwards how that object could be achieved.

Finally, he read in *Flight* a leading article relating to the development of air transport in South America and pointing out the great work done by the French and the Americans and asking why Great Britain, as usual, was lagging behind. He would like to point out that that was not due to a lack of enterprise on the part of operating companies or of manufacturers. It was due to a lack of enterprise on the part of the Government, who would not spend money to subsidise the line as the French or American Governments did. He believed the total subsidy paid to the French company was somewhere near a million sterling. Generally speaking, one wanted to be very careful in criticising developments abroad, because it was not always fully realised that without a very extensive subsidy from the Government such development was not possible.

Sir Dennistoun Burney, Bart.: Many of the questions he had wanted to put to the author had already been framed by other speakers. One question which he did desire to ask was whether the falling off of passengers was in any large measure due to the air sickness from which many people suffered in air transport. If that was so, had there been any experiments made as to the difference in air sickness as between the small aircraft and the very large flying boats such as the Dornier? It had always seemed to him that the large flying boat would have to be used not only for the inter-continental and inter-state airways as well as for the longer distances. If it were a fact that with a large machine such as a flying boat air sickness could be overcome—just as with the Mauretania

one did not get sea sickness as in a destroyer—then it seemed to him that it was a very fundamental consideration from the point of view of the ordinary passenger. He desired to know what was the expert opinion on that one point.

Another factor which he thought ought to be stressed at every meeting of that kind was that unless real international co-operation were obtained a commercial flying service could never get very far. He hoped that as much as possible would be done to eliminate all the interferences with passengers—customs and the like—which were experienced at the present time. In conclusion, he wished every success to the author and his company.

Brigadier-General Sir OSBORNE MANCE: The author had not laid any great stress on night flying for passengers except by way of enabling air services to complete their ordinary day journeys with equal reliability in the winter as in the summer. He took it that all night passenger services were not likely to be popular, at least not until that distant day when sound-proof sleeping compartments were possible, but he would like to suggest a method whereby night flying could be used for passenger traffic with some effect. At present one did not save any business time by travelling by air between Berlin and London. Travelling by air he would have to leave Berlin between 11 and 12 in the morning, and would reach London between six and seven in the evening, whereas, by leaving Berlin after one o'clock p.m., nearly two hours later and taking the railway and sea route via the Hook of Holland, he would get to his office one hour earlier than if, having made the air journey by day, he had slept at home. If the air services could be co-ordinated with the railway services so as to leave Berlin by air at the latest possible hour to enable the passenger to catch the night boat at the Hook of Holland (or, in the reverse direction, to leave London at the last possible hour so as to overtake the Nord express, say just beyond the German frontier) several business hours would be gained, and he believed there would be a considerable increase in traffic owing to the natural advantages of the air service. This seemed to be a commendable instance of the proper co-ordination of different means of transport in the interests of the community.

It would be interesting if the author could give some of his views on the future of air ports. Were they going to be State-owned? He hoped not, as it would increase the likelihood of further barriers to international trade. Were they going to be owned by the principal air company or by independent corporations? Although Herr Wronsky had expressed the view that Europe was saturated with air transport companies, surely he must envisage a large increase in private flying, including private goods flying in air lorries belonging to commercial and industrial companies. Would that class of flying be admitted to the air ports of the air companies, just as yachts and tramp steamers were now admitted to the sea ports of all countries, or would it be necessary on operating ground or for reasons of safety to limit the use of air line ports to public services?

An interesting question would arise as soon as air transport could be operated on a paying basis. The cost of an aeroplane was not very great, and if public ground services were available numerous small operators would tend to enter into the field. If they could buy their aeroplane "on credit," they would not even wait until the service was likely to pay its way. There was little doubt that such services would be started. In this country and in Germany there had been trouble enough in connection with the licensing question on roads. That was a national question; but the licensing of air services would be an international question, and he rather wondered whether anything had been done in preparation for it. He would like to know how the author would propose to regulate the licensing of air vehicles for public services, and how he imagined this particular question was likely to develop.

He echoed the wish of Sir Sefton Brancker that air flying might be as free as possible. The question of co-ordinating the different national services was

quite another matter. That ought to be a commercial and not a political matter, but if there were going to be any political restrictions on the movements of aircraft based on nationality, then he felt absolutely with Sir Sefton Brancker that it would be a long time before air services would be made to pay.

Major Woods Humphrey: He did not propose to add to the formidable list of questions which the Master of Sempill and others had put. Herr Wronsky had stressed the need for greater co-operation. The air companies of Europe did actually co-operate enormously to-day, but where the real co-operation was needed was between the Governments. He would not touch upon the delicate question of free flying, but on a more domestic matter, namely, such things as ship's papers and regulations. The air transport companies were staggering to-day under the burden of too many regulations. They were bound hand and foot by regulations, from which they really did need some relief. The ship's papers that were required for the India service amounted to the bulk of a despatch case about 6 ins. thick. It was too much for what was to-day a comparatively small aeroplane.

He would like to ask the President to take note of the remarks which had been made on the co-operation of the railways in Germany, and to convey it to his colleagues at the head of the railways in this country. He also endorsed Mr. Handley Page's appeal for more money to be spent on research. A considerable sum of money was spent, but very much more could be used with great advantage. Mr. Handley Page had drawn attention to the author's erroneous addition of a million pounds to the British subsidy. When he saw the figure given in the paper, he wondered where he could find that million, but it proved to be a mistake in figures.

It was generally thought that Imperial Airways did no night flying. As a matter of fact a considerable amount of night flying took place on their services running to India every week, particularly during the winter when the daylight hours were fewer than in summer.

Colonel I. A. E. Edwards: He had been interested in the point made by the author that various towns and cities in Germany provided aerodromes and subsidies in order to get the companies to connect them up with their services. A great deal of Herr Wronsky's time had been wasted in trying to persuade some of those municipalities not to come along with subsidies, because he could not run all the services required. The case was very different in this country, where the aviation concerns had almost to go on their knees to the municipal authorities to get them to produce an aerodrome at all. Then, when an aerodrome was produced, in nine cases out of ten they turned round and said, "How much rent are you prepared to pay?" In most cases an economic return on the capital invested is demanded as a fixed rent. He considered that that was not quite fair. The municipalities spent very large sums on making roads. Roads were made to facilitate transport, and the municipalities got no direct return out of their roads. Why, then, should they seek it in the case of their aerodromes?

There was another aspect of the case which was most important. Herr Wronsky had stated that the whole German nation appreciated the value of air transport. Every business man knows that if he has anything to sell he must advertise it, either by way of Press publicity or practical demonstration. Aviation was still rather an out of the way thing because it was comparatively new. Even to-day there were many people in this country who had never yet seen an aeroplane. The best way to advertise aviation was to let the people see aeroplanes. Aerodromes were a prime necessity. The point was important as an aspect of Empire trade, for trade could not be increased unless quick transport facilities were increased also. Air transport offers the best means of doing this and is therefore indispensable. The business men of this country, on the other

hand, could not be expected to appreciate and take advantage of the valuable services offered by Imperial Airways unless they were made familiar with aviation. The best way to make them so familiar was to have more aerodromes in this country.

Mr. L. A. WINGFIELD: The year 1929 had seen two outstanding events from the point of view of civil aviation. One of these was the signing at Warsaw on October 12th last of the International Air Code. Hitherto questions of insurance and insurance rates had been dealt with on the principle of a certain amount of practical experience and a certain amount of guess work. Now there had been handed down to those concerned a sort of Mosaic table ready made which would be in due course ratified. This would enable the air traffic companies and the insurers to know where they stood in a great many matters regarding which at present they were in the dark, with consequent reductions in insurance rates.

The second noteworthy event of last year was the establishment of an organisation in this country, which was unique, called the Guild of Air Pilots. Everybody was very anxious that the pilot should be thoroughly well educated, whether he had to obtain his education compulsorily or as a voluntary matter and on his own initiative. It was a matter for considerable congratulation that the air pilots did seek to organise their own means of education and thus to prove themselves a professional body capable of the dignity of that term and capable of controlling their own education. This move could not fail to increase public confidence in the safety of air transport.

He desired particularly to call attention to the question of training in blind flying, which Herr Wronsky had mentioned. Either the Government or an organisation such as the Guild must provide the means of enabling the pilots to get that training.

Mr. C. C. WALKER: Herr Wronsky had mentioned the very high cost of air transport, chiefly in connection with aircraft engines. It seemed to him that the reason for this high cost might be traced in the ancestry of the present transport aeroplane, which had evolved from war types, and also the fact that the engines used had mostly been designed as military engines. Again, the passengers had had to be attracted. A different kind of evolution had been going on lately which seemed to indicate that when transport companies could use less specialised aircraft they would be able to get them at a first cost of from £350 to £700 per seat, instead of the figure of £1,000 to £1,500 per seat deduced from the figures given by Herr Wronsky. It would be interesting to know how a road transport company would fare if it had to use, say, half a dozen coaches specially designed and constructed for its own use. With regard to certain of the other costs which Herr Wronsky had mentioned as being very high, the maintenance cost, the speaker thought, might possibly even be divided by three for a commercial engine in the future. In every direction in which one looked the future seemed to be very promising in respect to much lower costs, provided the transport companies did not require to have special machines designed for them.

Mr. F. RADCLIFFE (*communicated*): He had read with the greatest admiration and interest Major Wronsky's most informative paper and would be grateful if the author would give some information on the following points:—

(1) What appears to be the ideal type of "freighter" for use on long air routes, that is to say with reference to (*a*) amount of load that can be carried, (*b*) cruising speed necessary, (*c*) whether multi-engines or not, and (*d*) if multi-engined, must the aircraft be capable of flying with one engine cut out?

If this question could be answered, it would appear possible for the aircraft designer to attempt the production of a type which might bid fair to being standardised for ten years or so with all the resulting economies, for there is no doubt that aircraft with a life of ten years could be produced to-day without

sacrificing too much of the useful load carried. (The life of the aero engine is another matter, and it seems highly improbable that they can hope for a greater life from the petrol engine of more than four years.)

He submitted this question, because if the aircraft operator could really state what he would like then the designer will be better prepared to face up to the problem and find its ultimate solution.

(2) As the elimination of noise would be a great asset in increasing the comfort of air travel, is Major Wronsky at liberty to say what progress has been made in silencing the noise of the engines and airscrews during the past three years?

Reply to Discussion

Herr Wronsky: He had been asked many questions, and he would do his best to reply to them as briefly as possible. The first question asked was as to how many miles his service was flying by night? He did not know the exact figure, but he could indicate on the map the lines. There was one night service from Berlin north-eastwards to Konigsberg, and in the west there would be a service from Berlin to Cologne, and from Cologne to Paris and to London. From Berlin to London was 900 kilometres, and from Berlin to Paris about 850. For the time being his company had no night services with flying boats; only land machines were being used by night. As to which type of boat should be used on the ocean service, as he had stated in the paper, there would be in 1930 only one so-called trans-ocean service—namely, from South Spain to the Canary Islands. Mail only would be transported. The same type of machine was used on the other side of the ocean, in South America. On the more or less local lines from Germany into Sweden and Norway some new types of machines were still under trial, but not yet running.

As for the air-cooled engine, so far as he knew, this was now used to a greater extent than was the case perhaps a year ago. It seemed to him that these machines were more used than the water-cooled engines. There was no company in Germany running an air taxi service except the Luft Hansa, which had a certain amount of such service.

He had been asked why the lack of German colonies was a factor in the non-development of long air lines. The answer was very simple. The ocean was free, but the air above a country was not free. Of course, a shipping company could go to any place in the world, but an aeroplane, or even a seaplane, could not do so. Therefore it was much simpler in the case of a country which had colonies to run long air lines. A Belgian company could run to the Congo, or a British company to India, but if the German company did so, there was no place on the other side in which to land.

Mr. Handley Page had asked him what he thought would make machines more safe. The obvious answer was better engines. Major Humphrey asked why England did not run to South America. He hoped it would not. There were three national companies already operating there—France, the United States, and Germany. He would be very grateful if they were spared a fourth.

The question had been asked whether the decrease of passengers was due to air sickness. The answer was in the negative. The decrease in passengers began only in 1929, whereas even as far back as 1919 when the service began air sickness was a fact to be reckoned with. In spite of air sickness, there had been an increase of passengers up to 1928. In bigger machines air sickness was not so much experienced, and in seaplanes it was experienced very seldom.

As for night flying for passengers, his company had not such a service because it was so uncomfortable. At present there was only one night service for passengers, namely, from Berlin to Konigsberg, and that took four hours only. If a service were to be instituted which would fly all night something in

the nature of sleeping cars must be provided. The passengers were, however, able to endure a journey of four hours at night sitting in chairs.

In Germany the air ports belonged to the municipalities. There was no air port at all belonging to the Government or the State. The municipalities formed a small company in which, however a State like Prussia or Bavaria would take shares. In some of the large air ports the Reich had shares. As to the question about tramp service, that was impossible in the case of the air. The characteristic of a sea tramp service was that of picking up goods occasionally, but in the case of air services the goods were always despatched in a hurry, and could not wait for an occasional and casual tramp machine.

One speaker had mentioned the resolution of Warsaw. On that matter Major Beaumont could reply much better than himself, because he was one of the experts with regard to the unfortunate resolutions made in Warsaw.

In conclusion, he apologised if he had not answered other questions whose bearing he had not understood.

A STUDY OF THE PHENOMENON OF SPIN IN AEROPLANES*

BY

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The spin is a mode of motion of which we know very little. The general public are inclined to look upon it as necessarily dangerous, but this we do know it is not. It is only in rare circumstances and under fortunately rare conditions that danger arises. Nevertheless there is ample warrant for its study, and for that study to be treated as one of high importance. New conditions of aeroplane operation are continually arising, the very increase of speed itself would ensure an entry into regions never before penetrated. Hence it is ever necessary to seek for remedies even before serious difficulty has arisen; this anticipating action always seems to me to be absolutely essential, and I am comforted by support in this view from no less an authority than Francis Bacon, who, in his essay " On Innovations," wrote: " Time is the greatest innovator; and if time in course alters things to the worse, and wisdom and counsel shall not alter them to the better, what shall be the end?"

So we have ahead of us the difficult task of diagnosing not so much actual diseases as mere symptoms, and of devising in anticipation suitable remedies. Spins from which recovery is difficult may be rare, but, since from time to time they are reported, a vigorous investigation becomes necessary. Though that investigation is far from having been completed, indeed in some ways it is little more than begun, the interest taken by everyone in flying makes some account of our present efforts worth attempting, whilst the very complexity of the phenomenon is in itself a challenge.

The Spin

The first step will be to describe what constitutes a spin, why certain forms of spin present difficulty, why the obvious remedies fail, and the form which the studies now in hand have taken.

Almost all aeroplanes are built now-a-days to be stable in flight; if any small disturbance to their normal attitude occurs the craft tends by its own virtue to return to its previous attitude. The naval architect has always aimed so to design ships that they have this great quality—indeed, a ship whose stability depended upon the clever balancing action of its steersman would be decidedly unpopular.

Now, how does an aeroplane achieve stability? If one suspends a model aeroplane from a point above its centre of gravity it hangs in stable equilibrium. If slightly displaced it returns. When gliding in flight the upward pull of the string has to be replaced by the resultant of all the upward air forces on the wings and tail plane. If stability is to be obtained, this vertical resultant must pass through the centre of gravity of the craft. The usual way of insuring this is to give an upward tilt to each wing (the dihedral angle) so that the air forces

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on the two sides are inclined and meet at a point in the vertical plane of symmetry. The relative inclinations of wing and tail plane can be adjusted in just the same way, and thus the resultant of all the vertical air forces is made to pass through the centre of gravity so that the aeroplane behaves as though suspended at an imaginary point above it. This is the condition of ordinary straight flight; centrifugal force does not come into the picture. With circular motion, however, it does. The aeroplane banks as it turns, the air forces bank with it, and their resultant force balances gravity by its vertical component and the centrifugal force due to the turn by its horizontal one. Hence motion in circles can be just as steady and just as normal as in straight flight. Inconvenient and even dangerous as the actual spin may sometimes be, the spinning aeroplane is not, so to speak, conscious of doing anything wrong. Its behaviour is purely normal and quite virtuous. There is nothing in it to suggest the vicious circle. When the radius of the turn is made gradually less and less the angle of bank grows greater and greater until the vertical component of the air forces can no longer balance gravity, and the nose drops; the motion then becomes a kind of tight corkscrew. The motion is still steady and is quite safe. It is safe because the pilot can convert the motion into ordinary straight level flight whenever he wishes to do so. If, however, the corkscrew is made tighter and tighter the motion of the aeroplane may suddenly change to one in which the air forces on the machine will automatically tend to make it tighter still. This is the spin.

Before the essential features of the phenomenon of spin can be grasped it is necessary to consider in slightly more detail the nature of the forces which act on the wings of an aeroplane.

Autorotation

Aeroplane wings are of various shapes—some have concave under-surfaces and some convex—but all alike when inclined at an angle to the wind (the angle of incidence) give rise to an upward lift force, and a small rearward drag. It is important to notice the manner in which the lift force changes as the angle of incidence increases. To begin with, the lift force doubles for each doubling of this angle, but once the latter has reached a certain amount the lift force increases less rapidly until at a particular angle (known as the angle of stall and usually about 20 degrees) the lift force ceases to increase at all, and instead falls off rapidly as the angle is still further increased. When this happens there is produced a new phenomenon altogether. For if any sudden "bump" in the atmosphere causes the right wing (let us say) to drop and therefore to meet the air at a steeper angle, the lift force on that wing will *ipso facto* become less and the wing will tend to drop still further. In fact the whole wing will tend to go on turning. This is the phenomenon of autorotation. It can easily be exhibited in a wind tunnel by so mounting an aerofoil about a suitable axis as to give it a large angle of incidence; once the air stream is turned on the aerofoil will be found to be quite ready to rotate in either direction once some external cause has given it an initial push in that direction. The speed of autorotation depends upon the aerofoil section and the angle of incidence. In the case of a complete aeroplane it depends also on the disposition of the wings, particularly in relation to each other, and upon the arrangement of parts in the tail of the machine. It is the existence of the many factors which govern the occurrence and speed of autorotation which makes the study of the spin so complicated, that unless the problem is reducible to a few bare essentials a purely theoretical solution is hardly to be anticipated.

When describing the tight corkscrew as a mode of motion I mentioned that this motion might suddenly change to the spin. This will happen if the angle of incidence should rise to the value at which, for that particular wing

section and aerodynamic arrangement, autorotation sets in. Thereupon the forces acting on the aeroplane speed up the rotation and tend generally to take charge. Sometimes the machine is said to be " locked into " the spin, but this language, though understandable, is really over strong, since the pilot by putting down the nose of the craft can bring the angle of incidence below that of autorotation; at once the autorotation couple dies away and the spin ceases. How is a true mental picture of this complicated motion to be made? There are the resultant air force, the centrifugal force and the gravitational attraction all acting on the aeroplane. We know that the last-named always acts vertically downwards, whilst the centrifugal force acts at right angles to the axis of spin. For equilibrium these forces must be balanced by the air forces, hence the resultant of these latter must have a vertical component equal to the weight, a horizontal and radial component equal to the centrifugal force, and a horizontal and tangential component of zero. This last has to be zero, since in steady motion there can be no acceleration in that direction, and any force necessary to drag the tail round must be supplied by a suitable component of the air forces which act on the aerodynamic surfaces. The resulting motions are known, but no disentanglement of the various air forces due to lift, drag and sideslip has yet been made.

It was Bairstow who first suggested that the phenomenon of spinning could be imitated in a wind channel by setting an aerofoil at such an angle that self-rotation must occur. This is made clear by an Aeronautical Research Committee report dated October, 1918. In this report Relf and Lavender showed, not only why autorotation took place, but how to calculate the rate of spin. Model tests showed excellent agreement with their prediction. The rate of spin was found to increase with the angle of incidence, and in a chosen example the rotational speed rose from about $1\frac{1}{2}$ spins per second to two spins per second, when the incidence was increased from 20 degrees to 30 degrees.

It is clear from what has already been said that a lift curve which did not drop after the stalling point would be much less likely to lead to autorotation, or would in any case delay it to so large an angle of incidence that it would be very rare for an aeroplane to be in the attitude at which spinning could occur. The so-called " flat-topped lift curve " has this virtue in varying measure, as also have aeroplanes with slotted wings, for then the stalling angle is very large, and could usually only be reached, if at all, by a deliberate jerk to the whole machine. Getting into a spin would then be a piece of voluntary acrobatics and not a pitfall awaiting the unwary. " Pitfall " may seem a strong word, especially as the phrase of " locking into " a spin has been deprecated, on the ground that after all the pilot holds the key of the motion in the right use of his control levers. It seems, however, that certain forms of aeroplane have so high an autorotation couple that given time to attain the full corresponding rate of spin, the centrifugal forces, due to the unsymmetrical distribution of mass in the aeroplane, may oppose and overcome the control force exerted by the pilot's actions, and this may happen the more readily on account of the spin having become so flat (the aeroplane being less inclined to the horizontal plane than the vertical) that the control organs in the tail, in the fin and rudder, are shielded from effective action by the tail plane; and at the same time the physiological action of the rotational forces on the pilot may hinder his actions. If one casts a kind of airstream " shadow " at 45 degrees behind the tail plane, it will be seen that but little of the fin and rudder area can be effective in slowing-up the undesired rotation, or indeed in affecting it in any way. The most elementary way of preventing this rapid spin from developing is to increase the size of the vertical tail surfaces, the fin and rudder, and to lengthen the fuselage so that a greater leverage is available. This leads to an increase of weight in the tail, and puts the centre of that weight still further aft; both these actions lead to

an increase in what are called the inertia couples due to the centrifugal force. The effect of these inertia couples is, as I will describe in a moment, to oppose the pilot's control of the machine, and so neutralise wholly or partly the good effect, from another point of view, of the larger tail surfaces and greater leverage. Nevertheless, there is sometimes an advantage on balance to be gained in this way, and for some time a ready criterion of spinning tendencies was used in America, which depended principally upon whether or not the tail organs were inside a semi-circle based on the wing span.

Inertia Couples

The effect of an inertia couple can be illustrated by taking the simple case of a rod having equal heavy masses at each end and pivoted at its centre of gravity. If one holds such a system at arm's length and turns round rapidly, the rod takes up a horizontal position. This happens because the centrifugal force on each mass is proportional to its radius of rotation, hence the mass which starts farthest out tends to go still farther out, and stability is only reached when the rod is at right angles to the axis of rotation. If a second similar rod were fastened at right angles, the forces upon it would balance those on the first rod. The combination would be neutral, and would take up a neutral position. Hence, an aeroplane with its masses symmetrically disposed would be free from such couples, and free, therefore, from the peculiar difficulties of a flat spin. In practice, however, aeroplanes cannot be so made, and, as a fair instance of what occurs in practice, the case of the well-known Bristol Fighter aeroplane may be cited. Here, the moments of inertia about the longitudinal axis and the transverse axis are found to be about equal, whilst that about a vertical axis is half as much again.

A simple calculation shows that for any given rate of rotation this disturbing couple reaches a maximum when the fore and aft line of the aeroplane is inclined downwards at 45 degrees. Once that angle is exceeded the couple grows less. When, therefore, an aeroplane is being brought out of a very flat spin the pilot has to exert a control not merely large enough to balance the inertia couple at the moment, but large enough to overbalance this growing couple as the barrier angle is reached. The barrier angle will come at exactly 45 degrees if the rate of spin remains constant; if it does not it may be somewhat above or below this angle. But a barrier there will in general always be, and recovery from any flat spin must depend on its being satisfactorily surmounted.

A typical pilot's impression of the change from the ordinary spin to the flat spin appeared in one report as follows: "After the first two or three turns, which were relatively steep, the nose came up and the machine settled down to an exceptionally steady spin at moderately large incidence and a quick rate of rotation. There was no noticeable jerkiness during the turn."

Method of Study

So much for what the spin is and what causes it. We come now to the best way to study it. This can be done by employing models or by the use of full-sized aeroplanes. The latter method avoids uncertainties due to any possible "scale effect," *i.e.*, failure of the model to represent truly the motions of the full-sized machine, but adds the greater difficulty of making accurate quantitative measurements when in free flight, and adds the risk of crash. Experiments with models have been made in wind tunnels and in free flight. Small light models, to one-twelfth or one-twentieth scale, have been made at Farnborough out of balsa wood, and these have been dropped through a free fall of 90 feet in the large balloon shed. Cinematograph records have been made, and the motion subsequently measured up from the films. In certain of these model-dropping experiments a Bristol Fighter model was used, and success attended

the effort to reproduce various types of spin. In this particular machine the rudder was found to be surprisingly effective as a controlling organ, and if the spin were started against this control it was stopped in six turns.

Of all the various controls the aileron is normally the least effective—that is, the ordinary type of aileron. If, however, the possible aileron angle is arranged to be *very* largely increased the spinning motion is affected. The following account of a model-dropping experiment at Farnborough will serve alike to indicate this aileron effect, and to illustrate the nature of this mode of this form of experimentation.. A one-twentieth scale model of a Bristol Fighter was used. Ailerons were fitted to the upper and lower starboard wings, and provision was made for moving any of the controls at a predetermined time during the spin. This was done by means of a spring-loaded dash pot with a variable air leak. The model was released from a swinging pendulum just under the roof of the balloon shed in such a way that it was at release moving horizontally at its stalling speed with 10 degrees of sideslip. It was launched with full left rudder and with the elevators fully up. With ailerons neutral the model completed $4\frac{1}{2}$ turns of a left hand spin in as many seconds. A further test was then made with control release set to move the outer aileron to an angle of 65 degrees after an interval of $2\frac{1}{2}$ seconds, with the result that the model ceased spinning within about half a turn.

The flat spin with this model was found to be one of very small radius, the mean angle of incidence appearing to be about 75 degrees (the smallness of the radius in flat spins is of course well known, as is the consequent extraordinary difference sometimes found in the centrifugal forces acting on the pilot's and observer's bodies). Whereas in the ordinary spins of this model $4\frac{1}{2}$ turns were made in $4\frac{1}{2}$ seconds, in the flat spin 11 turns were completed in $5\frac{1}{2}$ seconds, and the axis of the spin, instead of being well ahead of the nose, came close to the centre of gravity.

Sometimes the little model was made automatically to centralise its controls during the fall, and the effect of this on the resulting motion was studied. Sometimes the models were set into a spin at the moment of release, and the effect of variations in wing arrangement ascertained. In this way the effect of stagger, wing gap, decalage and other features can be studied rapidly. This has proved a useful method of investigation; it is safe, speedy, and very picturesque.

The other way of using models is to mount them in a wind tunnel and measure the forces which arise during the spinning motion. This is an exceedingly difficult experiment to carry out, for the motion is complex, and it is no very easy matter to lead out the connections which will enable the couples about each of the axes to be measured. It is not so difficult to measure the moment about the autorotation axis, the axis of spin, and this investigation is now in hand. The amount of the autorotation moment will of course give a measure of one at any rate of the forces tending to keep the aeroplane in the spin. The fuller experiment will, however, be undertaken in one of the N.P.L. wind tunnels as soon as the apparatus is ready.

Yet another form of wind tunnel test is due to Professor Betz. This consists in measuring the rate of autorotation of a hollow aerofoil in which air can be allowed to pass internally from one wing tip slit to the other. These slits are placed in the upper surfaces and are parallel to the wing spar. Measurements have been made in Germany with these slits in different symmetrical positions and with or without a free internal air passage. The result is found that with the best arrangement there is at some cost of maximum lift a distinct decrease of the tendency to autorotation, and that this gain is directly associated with the free lateral passage of the air inside the wing. The following explanation of the action is given by Schrenk.* It is known that the motion of a rotating wing

* Zeits. f. Flugtechn. u. Motorlufts, November 14th, 1929.

produces different angles of incidence at corresponding sections of the two ends, such that at the rising end the flow adheres to the upper surface whilst at the other end it tends to break away. For this reason the lift on two such corresponding elements is not necessarily the same, and in no case will the pressure distributions on the elements coincide. The flow from slit to slit through the wing is caused by such differences of pressure, and acts in such a way that at the wing tip at which the flow breaks away from the surface the flow is improved by suction of the boundary layer towards the interior of the wing; at the other end the flow is rendered worse by the air streaming out of the slit. It follows that any autorotation there may be will tend to be much slower and therefore more controllable.

The first full scale experimental and mathematical investigation of spinning was that by Lindemann, Glauert and Harris. This work was carried out at Farnborough, and in their report to the Aeronautical Research Committee, dated March, 1918, full details of this very courageous investigation are given. It is noteworthy that they made use of streamers attached to outrigged spars, and by their use measured for the first time the angle of incidence.

At the present time full scale research on spinning is included in the research programme at Farnborough. Indeed the phenomenon is one which requires continuous study, since each new development of aeroplane design may bring in some new aspect of the spinning problem.

In addition to this work there are the normal "performance tests" on spinning which are carried out at Martlesham on all new types of aeroplane, during which each machine is spun through not less than eight turns to right and to left with varying positions of the centre of gravity, and no machine is passed for service unless it can be readily brought out of such a spin by the normal use of the controls. Intrepid pilots are needed for such tests on new machines, and it does sometimes happen that the obstinacy of the aeroplane in its motion requires the pilot to resort to his parachute, though curiously enough the mere rising of the pilot in his seat with a view to leaving the aeroplane has on more than one occasion caused the machine to come out of its spin at once. Sometimes the engine throttle can be used as a control on the spin, since change of engine torque will of course tend to roll the machine to a new attitude. Spinning tests have also been undertaken by the Cambridge University Air Squadron with the help of Professor Melvill Jones. In these tests the wool tuft method due to Flight Lieutenant Haslam has been found of use. This consists of mounting numerous little tufts of wool on the upper surface of the wing and watching (in some cases taking cinema records of) what happens when the machine gets into various attitudes. As I have already mentioned a rather similar method of experiment has been used at Farnborough, in which long streamers have been attached to the wing tips or other aeroplane parts and their motion studied in the spin.

It is not pretended that the behaviour of these streamers is understood, but it is hoped that the continuation of the research will bring such knowledge as will enable these results to be usefully interpreted. As an example of the complexity the following extract may be given from a Farnborough report: "It was decided to investigate the practicability of recording the direction of the air flow over various parts of the aeroplane while spinning by photographing streamers. Outriggers were fixed to the lower planes. These were attached to the front spars and projected two feet beyond the wing tips, fabric streamers four feet in length being attached to the ends. Streamers were also fixed to tubes projecting 9 inches in front of the leading edge of the tail plane three feet from the plane of symmetry. . . . Then inclination of the wing tip streamers was found to vary in phase with the oscillation of the spin. In the left hand spin the mean inclination of the inner streamer to the wing chord was 73 degrees, and that

of the outer streamer 24 degrees. . . . The photographs of the tail plane streamers were less satisfactory, and it was only possible to determine the inclinations of the inner streamer, . . . the mean inclination of the streamer was about 15 degrees from the Z axis towards the rudder, which implies a lateral flow at the streamer which is opposite in direction to that caused by the rotation of the tail. An inward sideslip of the order of 20 degrees would satisfy these conditions." These experiments show that in nearly flat spins, where the rate of rotation is high and the vertical velocity small, the tail unit has to operate in air previously disturbed by the passage of the wing tips. This disturbance of course does not add to the effectiveness of the tail control organs. The sole merit to be found in the motion in a flat spin is that the vertical velocity is quite often so small that little more than a crashed under-carriage results from hitting the ground. In this type of spin the wings are acting rather like those of an autogyro, but very inefficiently, of course, since one wing is entering the air by its trailing edge.

Another method of full scale test making use of a cinematograph camera on the ground has been employed in Germany. The size of the image on the film gives a rough measure of the distance away of the aeroplane, whilst the angular distance and the time are readily noted. Cinema methods are also in use in U.S.A. When new types of aeroplanes are tested at the R.A.F. Station at Martlesham in order to ascertain their performance under all conditions of flight, they need to be spun both to left and right and not merely in one direction only. This is because of the influence of the direction of engine rotation upon the slipstream, and because of the gyroscopic couple due to the rotating engine and airscrew which will try to depress the nose of the craft in one case and raise it in the other. Recovery is required to be simple and sure even when this gyrostatic couple assists the inertia couple in opposing the pilot's actions.

At first it was not realised that an aeroplane that could easily be brought out of a spin of a few turns would not necessarily be easily brought out if the spin were continued for a large number of turns. The reason for this is not certainly known, but it can hardly fail to be associated with sheer lapse of time allowing the forces opposing recovery gradually to raise the nose of the machine and so get it into a condition in which for one reason or another the pilot's controls are less effective. Nor has it long been realised that the effect of small differences in the actual mode of entry into the spin can persist even after many turns, and so sometimes render recovery unexpectedly difficult. This explains the previously puzzling question why pilot A's report on the controllability of a given machine in a spin differs entirely from pilot B's. The explanation no doubt is that the two pilots follow a slightly different technique in putting their aeroplanes into spins. For research investigations it is feasible always to employ the same technique, but during the performance testing of new aircraft consideration must be given also to what is likely to happen when this definite technique is not followed.

The Woof

A recent discovery is the "Woof." This is a word coined by the Martlesham pilots to describe the unsteady form of spin sometimes met with, in which there is an oscillation in pitch combined with an oscillation in spin, so leading to a very uncomfortable motion. This is so little understood at the moment that one of the Air Ministry Scientific Research Staff, in a recent report, had to admit that "the origin of the air forces necessary to maintain this fluctuation in attitude is at present a mystery, and this obscurity is typical of the present stage of the spinning problem." In one recent test the jerkiness of the motion could be distinctly seen from the ground. The unevenness of rotation was accompanied by an appreciable oscillation in pitch, the rate of rotation decreasing as the nose

of the aircraft rose and increasing as it fell. Accelerometer records showed the mean period of the pitch oscillation to be rather over 5 seconds, whereas the corresponding mean times per turn of these spins was only about $4\frac{1}{2}$ seconds. The complexity of the motion may be inferred from the different periodic times.

It may be, of course, that long before these highly complex phenomena are fully understood some novel constructional device will be produced which will at once render all spins controllable. A device which went so far as to prevent spinning altogether would probably not be desirable, since it might also prevent the useful manœuvre of the " roll."

It is true, I fear, that in these matters we ask a great deal. We ask that the aeroplane shall do everything that the pilot wishes, but shall have no will of its own other than a moderate wish to remain the right way up, but even this not to be thrust too prominently before the pilot's notice. We want a docile machine. We want in fact an amount of docility which though often sought is but rarely found, even in humanity.

THE FORCES ON A YACHT'S SAIL

BY

T. TANNER, A.C.G.I., D.I.C.

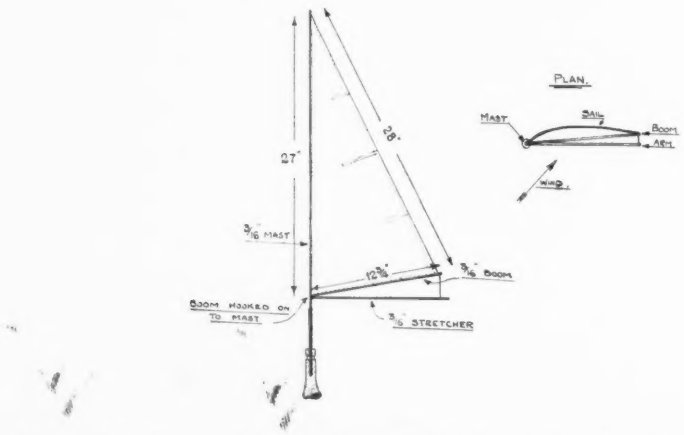
In the following article an attempt has been made to present the characteristics of a sail by considering it as an aerofoil, the " lift " and " drag " being replaced by two forces mutually at right-angles in a horizontal plane, one force corresponding to the drag, acting in the same direction as the relative wind. It appears that skill in the art of sailing could be reduced, apart from other considerations, to ability to set the sail in the required position determined by its aerodynamic characteristics.

That the drag force is in the direction of the relative wind is important because in the tests the model was stationary, whereas in practice the vessel is possibly moving in any one of a number of directions with about one-third of the actual wind velocity.

Further, it appears that if the hull resistance, or resistance to motion, of the particular type of vessel was known or could be pre-determined by model experiments in a " Froude " tank, the speed of the vessel in any given wind and in any direction could be predicted from the wind tunnel tests.

The experiments were carried out in the four-foot wind tunnel at the Royal College of Science, the normal N.P.L. type of lift and drag balance being used for the measurement of the forces. The sail model, known technically as a Bermuda rig, is illustrated in Fig. 1, as is also the method of support. Tests

FIGURE 1).

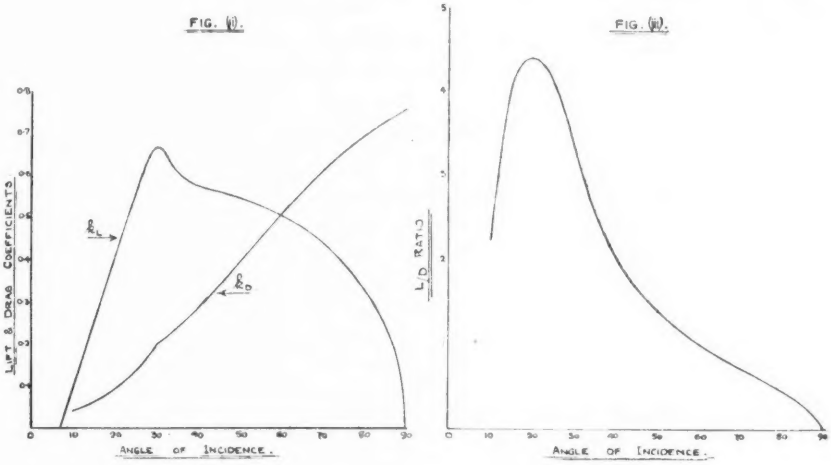


were carried out at a wind speed of 20 feet per second and a correction was made for the forces on the horizontal arm and the spindle. No correction was made for that part of the latter which constitutes the mast, as this was considered to be an essential part of the sail.

The lift and drag coefficients and the values of the ratio lift/drag for various angles of incidence are given in Table I. The force designated " lift " is that which acts in a horizontal direction perpendicular to the relative wind and not vertically as in normal aerodynamic practice. Graphs of lift and drag coefficients and L/D ratio against angle of incidence are illustrated in Figs. 2 and 3, and lift coefficient against drag coefficient is shown in Fig. 4.

TABLE I.

Angle of Incidence.	Lift Coefft. (k_L).	Drag Coefft. (k_D).	Ratio L/D.
10	.0935	.0419	2.23
15	.2424	.0596	4.07
20	.406	.0922	4.40
25	.553	.1342	4.12
30	.663	.1992	3.33
35	.604	.237	2.55
40	.572	.288	1.99
50	.545	.396	1.38
60	.505	.505	1.00
70	.436	.612	0.71
80	.330	.697	0.48
90	.205	.754	0.27

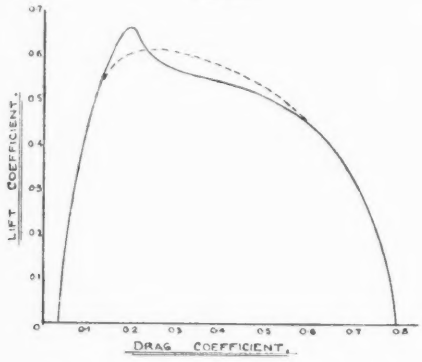


Before commencing the tests the main boom was tied down to the horizontal arm reasonably taut and this arm was set along the wind, which position corresponds to zero incidence. The angle of incidence was then measured by the angle turned through by the arm. Fig. 1 includes a plan of the arrangement. At large angles of incidence the boom and horizontal arm were out of alignment so that when the arm had been turned through 90° the incidence of the boom was probably about 87°.

It will be seen from the curves that the maximum value of the lift coefficient (k_L) is 0.665 at about 30° incidence and the ratio L/D has a maximum of 4.4 at about 20° incidence.

If the model is considered as an aerofoil the results are poor owing to the high values of the drag coefficient (k_D), but as a sail the important force is a combination of k_L and k_D, the relative importance of each depending upon the angle by which the course made good lies " off " the wind, that is to say,

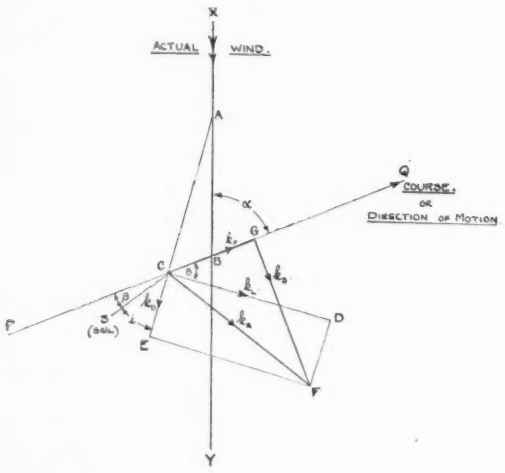
FIG. (iv).



the angle between the direction of motion and the wind. This point will be considered again later.

Now suppose the direction of motion of a vessel is PQ (see Fig. 5), which makes an angle " α " with the direction of the actual wind represented by XY.

FIGURE (v).



If the vector AB represents the wind velocity (v_a ft./sec.) and the vector CB, the speed of the vessel through the water (V ft./sec.), AC will represent the relative wind (v_r ft./sec.). " V " is made up of a velocity in the direction of the centre-line of the vessel and a small component perpendicular to it, usually

referred to as " leeway." The conditions of the wind tunnel test are represented by a stationary vessel at C subject to the relative wind AC, and the forces on the sail will be represented by k_L and k_D as shown, giving the resultant force coefficient CF. This resultant may be resolved into two other force coefficients, namely, CG in the direction of motion and GF perpendicular to it. We will call CG the " coefficient of forward thrust " (k_F) and GF the " coefficient of side thrust " (k_s). These two forces are balanced by the reactions of the hull in the water. The effect of the vessel moving steadily in a direction inclined to its centre-line is to produce a force inclined to the direction of motion such that its components along the direction of motion and perpendicular to it balance the forces produced by the wind on the sail. The ultimate result is steady motion in a given direction and a couple causing the vessel to " heel." Then for maximum speed the sail must be set at such an angle as to make the component CG a maximum. If the angle between the lift coefficient and the direction of motion is denoted by " θ," then $k_F = k_L \cos\theta - k_D \sin\theta$, and for maximum speed this must be a maximum for the particular value of " θ " under consideration.

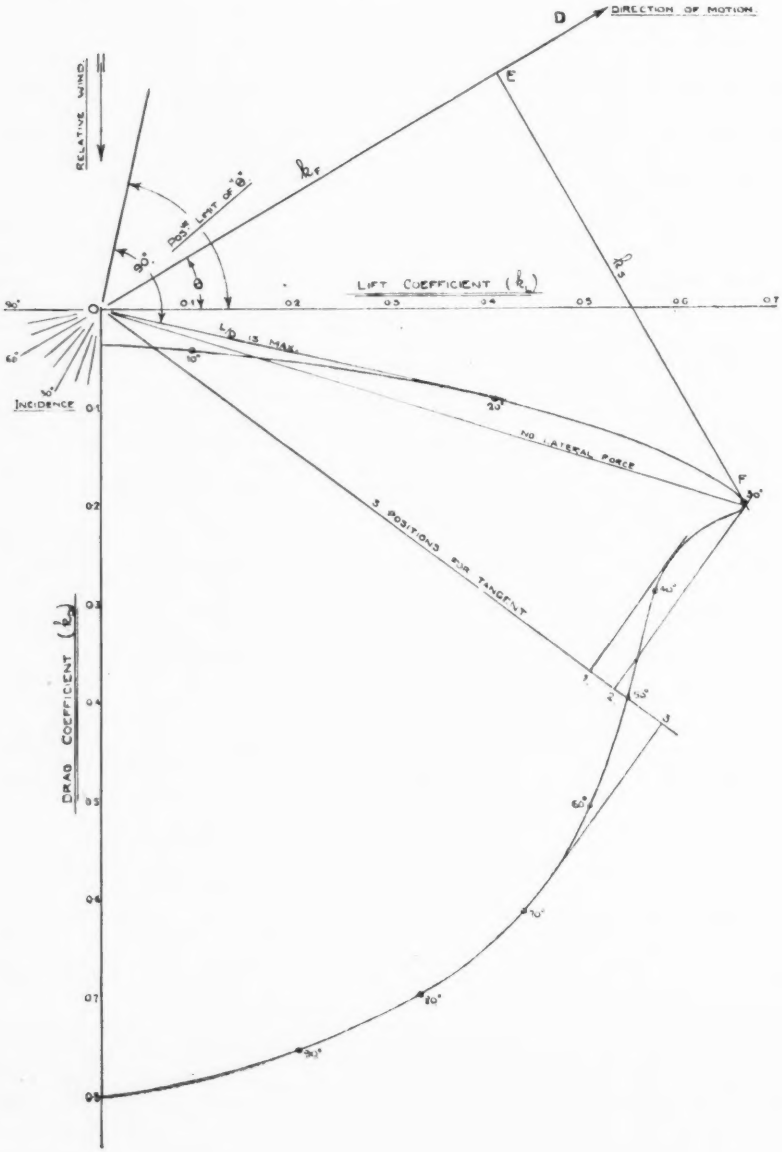
A graphical method for finding the maximum value of k_F is illustrated in Fig. 6, in which the curve shows the relation between k_L and k_D. Since the latter coefficient is in the same direction as the relative wind, the direction of motion may be represented by a line OD at an angle " θ " measured from the axis of k_L. Then the tangent EF to the curve which is perpendicular to OD will intersect the latter at a point E such that OE represents the maximum value of k_F and EF the corresponding value of k_s. If the value of " θ " is such that the best possible resultant (k_R) is perpendicular to the direction of motion, there will be no component in this direction, the force being wholly lateral. This condition occurs when the value of the ratio L/D is a maximum, and then " θ " will be given by $\tan^{-1}$ L/D. The limits of " θ " are therefore $\tan^{-1}(L/D)_{max}$ and $-90°$ which latter corresponds to the vessel running dead before the wind. Curves showing the variations of k_F and k_s with " θ " are given in Fig. 7.

A number of peculiarities arise from this graphical method due to the shape of the k_L/k_D curve. When θ is $-16.7°$, the value of k_F is 0.692 and there is no lateral force, k_F being equal to k_R, so that the vessel has no tendency to heel or to make leeway. For negative values of " θ " greater than $-16.7°$ there are generally three positions for the tangent, two of which give lateral forces to windward. In finding the values of k_F and k_s the tangent has been chosen such that whilst giving the maximum k_F it gives also a positive k_s, or a lateral force to leeward. This peculiarity would not arise if the centre of curvature was always within the curve as would be the case with the dotted line shown in Fig. 4, and it seems reasonable to suppose that the set (or camber) of the sail changes continuously in practice so that the k_L/k_D curve becomes similar to this dotted line, in which case the curves of k_F and k_s would be continuous. From a consideration of the angles of incidence (referred to the relative wind) shown in Fig. 6, it will be seen that for values of " θ " from the positive limit to $-16.7°$ the value of k_F is very sensitive to the position of the sail, whereas from $-16.7°$ to $-90°$, k_F changes very little with alteration of the angle of incidence, but k_s may change from positive to negative. This is possibly an explanation of the violent " rolling " which occurs when a vessel is sailing with the wind on the quarter on a " gusty " day, for a sudden lull in the velocity of the actual wind, while the vessel maintains its velocity through the water due to its own momentum, has the effect of considerably reducing the angle of incidence.

When the direction of motion is perpendicular to the relative wind the value of k_F is given by the maximum value of k_L, and when the motion is in the same direction as the relative wind, and therefore the actual wind, k_F is given by the maximum value of k_D. In Fig. 5, let SC represent the sail so that

it makes an angle of incidence "i" equal to SCE with the relative wind and suppose that "β" is the angle which the sail makes with the direction of motion. Then $\theta+\beta+i=90°$. Values of k_F, k_R, i and β for various angles "θ" are given in Table II. It will be clear at this stage that, unlike the aerodynamic con-

FIGURE (VI)



siderations of an aerofoil, when "θ" becomes negative the high value of k_D is an essentially valuable feature of the sail.

FIGURE (Vii)

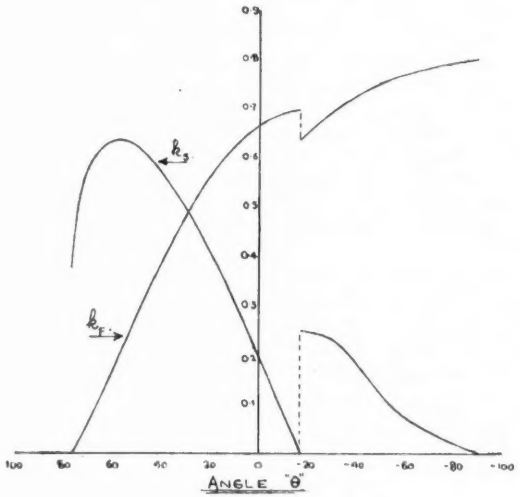


TABLE II.

Angle "θ."	k_F.	k_S	Angle of Incidence "i."	Angle "β."
77·2	0	·373	19	− 6.2
70	.063	·577	25.2	− 5.2
60	.166	.630	28	+ 2
50	.280	.619	29.3	10.7
40	.384	·570	29.6	20.4
30	·476	.498	29.9	30.1
20	·559	·407	30	40
10	.619	·310	30.2	49.8
0	.664	.197	30.5	59·5
−10	.689	.078	30.6	69.4
−16.7	.692	0	30.5	76.2
−20	.650	.243	55	55
−30	.692	.230	63.5	56.5
−40	.726	.179	69.4	60.6
−50	·752	.118	74·7	65·3
−60	·768	.060	79·5	70.5
−70	·778	.040	88.0	72.0
−90	·797	0	90	90

Method of Speed Prediction

The method of predicting the speed of the vessel on any course in a given wind is based on "trial and error" and the assumption has been made that the k_L/k_D curve is the same for all values of the relative wind velocity, that is to say, there is no "scale-effect."

Suppose the vessel is steering a course which makes an angle " α " with the direction of the actual wind of which the velocity is v_a (feet per second). It is now necessary to guess a value for the speed of the boat in order to determine the relative wind and the angle " θ." For this angle we may find the best value of k_F from the curve of Fig. 7 and the forward thrust on the vessel follows at once from $F = k_F \rho s v_r^2$, where " ρ " is the density of the air, " s " is the sail area and " v_r " the velocity of the relative wind.

Let us now assume that the total resistance " R " to the motion of a hull through water varies as the square of the speed. That is to say, $R =$ a constant $\times V^2$, where V is the speed. If the value of the constant be known from model experiments in a " Froude " tank we may find the value of V in this formula by substituting F (above) for R, since these must be equal for steady motion. This value of V should be the same as the assumed speed of the vessel if the first guess has been a good one; if not, we may assume V as the initial condition and repeat the calculation, and so on until the calculated speed is the same as the assumed speed.

Example.—In the following case, as no figures were available on the resistance of the hull, it has been assumed that the vessel is capable of running at 10ft./sec. before an actual wind of 30ft./sec. The relative wind speed will be 20ft./sec., and " θ " being $-90°$, the value of k_F will be approximately 0.8. This will give the necessary criterion for hull resistance.

Now since $k_F = \dfrac{F}{\rho s v_r^2}$

$F =$ a constant (A, say) $\times k_F v_r^2$.

Also, $R =$ a constant (B, say) $\times V^2$.

For steady motion, $F = R$.

$$\therefore \frac{V^2}{k_F v_r^2} = \text{constant}.$$

With the above assumption, $F = A \times 320$ and $R = B \times 100$.

Hence

$$\frac{V^2}{k_F v_r^2} = \frac{1}{3.2}$$

$$\text{or } V = v_r \sqrt{\left(\frac{k_F}{3.2}\right)}$$

To find the speed of the vessel when travelling in a direction at 45° to the actual wind of 30ft./sec.

Here, $\alpha = 45°$, and $v_a = 30$ft./sec.

As a first guess suppose the speed is 10ft./sec. The velocity of the relative wind (v_r) will be 37.7ft./sec., and the angle θ will be 55.6°. For this value of θ, k_F will be 0.215 and hence,

$$V = 37.7 \sqrt{\left(\frac{0.215}{3.2}\right)} = 9.77 \text{ft./sec.}$$

Now assume this value for the speed and repeat the calculation. " V " becomes 9.73ft./sec., which may be taken as the correct figure since it does not vary from the assumed value by more than 0.5 per cent.

Table III gives the speed of the vessel on various courses in a wind of velocity 30ft. per sec., as determined by this method and Fig. 8 shows the variations of speed with the angle α. It will be seen that a maximum speed of about 13.3 feet per second is attained when α is 90°, that is to say, when the

wind is "abeam." Discontinuity of course appears again owing to the shape of the k_F/θ curve.

FIGURE (viii)

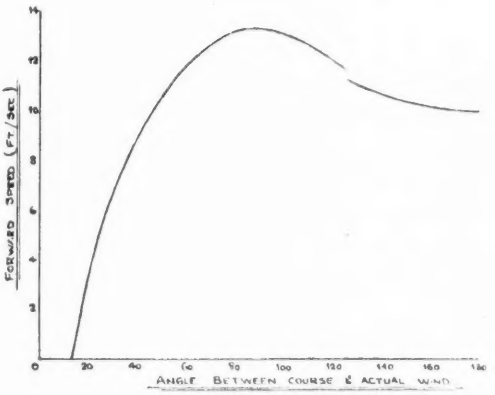


TABLE III.

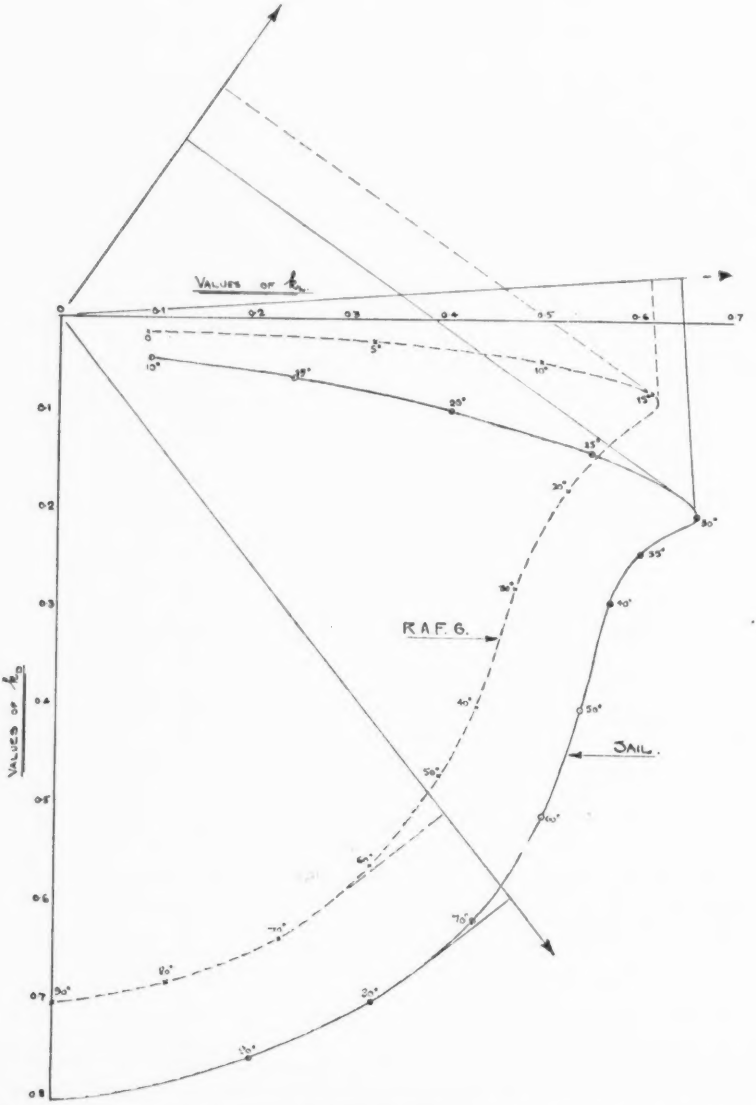
Angle "a."	Forward Speed of Boat (ft./sec.)	Angle "θ."
12.8	0	77.2
30	6.59	65.3
45	9.73	55.6
60	11.78	45.9
75	12.98	35.5
90	13.32	24.0
105	12.92	10.1
120	12.07	− 6.4
125	11.71	−12.6
130	11.02	−19.9
135	10.85	−26.2
150	10.36	−45.8
180	10.00	−90

The velocity to windward, the all-important consideration when "beating to windward," is given by $V \cos a$ and it can easily be shown that for the sail in question this is a maximum when a is approximately 46°. This corresponds very closely with the maximum value of the lateral thrust, so that the angle of "heel" will be a maximum at the same time, provided that the sail is set correctly.

In Fig. 9 the k_L/k_D curve for R.A.F.6 (aspect ratio 6) is shown together with that for the sail. This aerofoil section was chosen for the comparison simply because the figures for k_L and k_D up to 90° incidence happened to be available. For values of θ from $\tan^{-1}(L/D)_{max}$ to about 25°, the aerofoil gives larger values of k_F although its maximum k_l is smaller. This is due to the lower values of k_D (or higher values of L/D). For values of θ from 25° down to the angle for zero lateral force, the sail gives better results than the aerofoil because k_F depends mainly upon the maximum k_L and is little affected by k_D. Thereafter, round to $\theta = -90°$, the sail continues to give the better results, the influence of

k_L on k_F being gradually replaced by the influence of k_D, until at $\theta = -90°$, k_D is the only important factor.

FIGURE (ix)



In all cases, the best results for the aerofoil would be given at smaller angles of incidence, with a correspondingly larger angle "β" between the sail and the direction of motion.

WING-BEATS*

BY

J. D. BATTEN

In my little book, *An Approach to Winged Flight*, published in 1928, I advanced the view that the flight of all human gliders might fairly be regarded as a winged flight with locked wings.

I suppose that if the wings were unlocked they would flap upwards and the aviator would come down; but that if they could be unlocked and yet restrained by springs so strong that, until any other force were applied, they would retain their horizontal position, then it seemed credible that their movement would be under the control of the aviator and that, as soon as he knew how to exercise that control to his own advantage, he would actually be flying.

Starting from this point of view, the first task of all would be the discovery of springs of great strength and endurance and of extreme lightness. To this task I devoted myself. The annexed photographs show the measure of success which I have as yet attained.

Both the torses shown are composed of skeins of natural silk (silk " in the gum " it is called) as it comes from China. The upper torse has four skeins, the lower torse six. Each skein weighs $3\frac{1}{4}$ ounces and consists of a continuous thread about 27 miles in length. The thread is continuous because it is built up from the silk of not less than 12 cocoons twisted together, six and six, and as soon as the silk from one cocoon is spent, a fresh cocoon is attached and so the uniform strength and substance of the thread is maintained. [Reference: " Silk," by Luther Hooper, publ. Pitman.]

It will be noticed that the upper torse looks somewhat frayed and dishevelled. That is because it has now been on duty for five years, *i.e.*, from April, 1925, and has served for a great number of experiments. The untidiness is only superficial, the silk does not seem to have lost anything in strength or resilience.

The atmospheric changes which have occurred within that period, damp or dry, heat or frost, do not appear to have affected the silk even temporarily. In this respect its behaviour is very different from that of hemp or flax.

The skeins of the lower torse are of the same age, but after they had been used for a time (as shown in the photographs of my book), they were taken down and put away in a box. Last December they were brought out and put to the use shown in the present photographs.

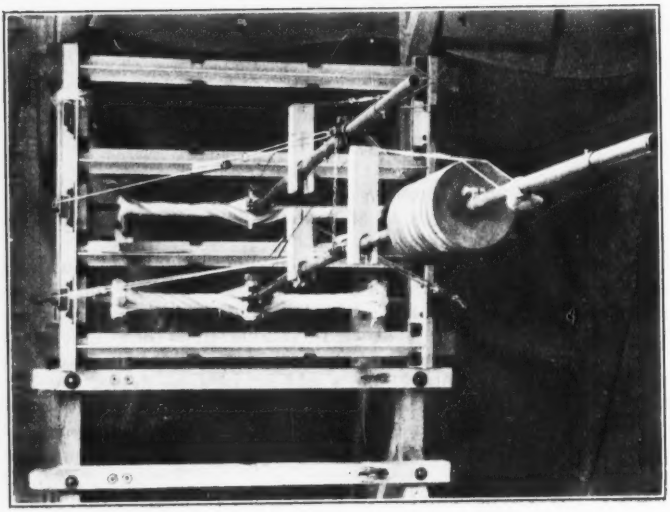
In these the two levers are seen linked together by a pair of chains. The chains can easily be unhitched and the levers operated independently.

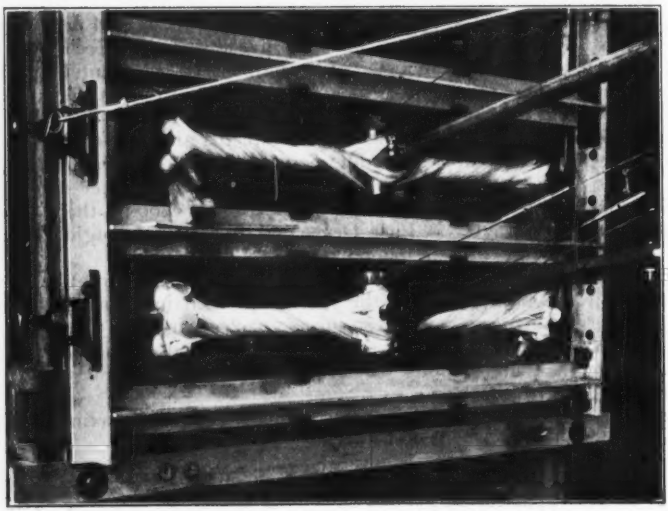
The weights shown are cast iron discs, each weighing 5 pounds. Since the photograph was taken I have added three more discs bringing the total cast iron weight up to 60 pounds. The centre of gravity of these is 60 inches out from the hub of the lever.

The action of the torses is regulated by tightening or relaxing the nuts of the bolts which take the end pull.

For the purpose of the photographs a curtain was hung behind the apparatus, but usually I should be standing there with my fingers on the butt end of the lower lever. By a slight repeated pressure of my finger-tips, I could induce a vertical oscillation of the lever through an angle of 60°, 45°, or 30°, as I chose. With a stop-watch I took the time of 100 such oscillations.

* This article is published as a matter of record of an interesting series of experiments.—ED.





I noted the upper limit of the oscillations by sighting the tip of the lever against marks on the wall opposite. The lower limit I was not able to observe from this position, but from the observation of others and from measurements which I have made, it appears that the angle below the horizontal is equal to the angle above the horizontal.

Although the angle is gauged by eye and the regulating impulse given by hand, the time readings show a consistence which is surprising.

For example, Feb. 25th, 1930:—

Weight 55 lbs., 60 inches out, angle 45°.

100	oscillations,	1st reading,	2 min. 46 sec.
100	,,	2nd ,,	2 min. $45\frac{2}{5}$ sec.
100	,,	3rd ,,	2 min. $45\frac{4}{5}$ sec.

Feb. 26th, weight 60 lbs., 60 inches out.

100	oscillations,	1st reading,	2 min. $51\frac{3}{5}$ sec.
100	,,	2nd ,,	2 min. $51\frac{4}{5}$ sec.

This consistency enabled me to make the following time records. In both series " weight " means the weight of the cast iron discs. Its distance out along the lever is read from the centre of the hub to the centre of gravity of the discs.

The actual weight of the lower lever is $15\frac{1}{2}$ lbs. and its calculated moment about the hub 596.75 in pound-inches.

The weight of the upper lever is $5\frac{1}{2}$ lbs.; moment 126.5 in pound-inches

The angle of oscillation is 45° throughout.

The end pull of the bolts of the torse is tuned to bring the lever to rest at, or a little above, the horizontal.

In the first series, plotted in Chart A, the weight is constant, but its distance out along the lever is changed. Weight 40 lbs.

Time of 100 oscillations:—

At lever length	30	inches,	$116\frac{1}{2}$	seconds.
,,	32	,,	120	,,
,,	34	,,	$122\frac{1}{2}$	,,
,,	36	,,	$125\frac{1}{2}$	,,
,,	38	,,	$133\frac{3}{5}$	,,
,,	40	,,	$137\frac{1}{2}$	,,
,,	42	,,	$142\frac{1}{2}$	,,
,,	44	,,	145	,,
,,	46	,,	$147\frac{1}{2}$	,,
,,	48	,,	150	,,
,,	50	,,	160	,,
,,	52	,,	167	,,
,,	54	,,	$171\frac{1}{5}$	,,
,,	56	,,	$174\frac{4}{5}$	,,
,,	58	,,	$177\frac{1}{2}$	,,
,,	60	,,	$188\frac{1}{2}$	,,

The " simple pendulum " curve, given for the purpose of comparison, is not from observation, but is set out from the formula

$$t^2 = (\pi^2/g)\, l.$$

As this formula assumes that the pendulum rod has no weight and as my levers have the weight and moment above given, the divergence of the general trend of my observations from the pendulum curve is accountable.

The noticeable daily curve is, I think, due to the fact that in this series the moment of the weight is *reduced* step by step and that the silk takes time to accommodate itself to the change.

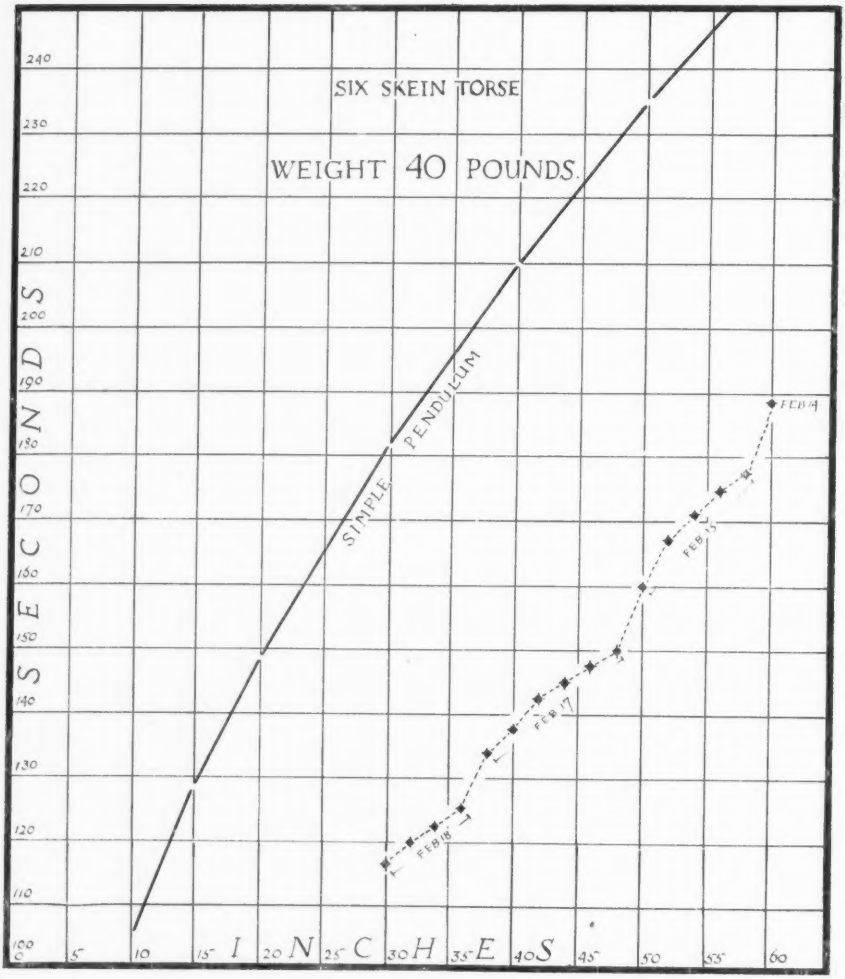

SIX SKEIN TORSE
WEIGHT 40 POUNDS.
SECONDS
240
230
220
210
200
190
180
170
160
150
140
130
120
110
100
5
10
15
20
25
30
35
40
45
50
55
60
INCHES
SIMPLE PENDULUM
FEB 18
FEB 17
FEB 15
FEB 14

CHART A.

In the second series, plotted in Chart B, the lever length, 60 inches, remains constant, but the weight is changed by the addition or removal, one by one, of the 5 lb. discs.

Time of 100 oscillations:—

(i) With six-skein torse only.

Weight	20	pounds,	$145\frac{1}{2}$ seconds.
,,	25	,,	154 ,,
,,	30	,,	$165\frac{3}{5}$,,
,,	35	,,	$176\frac{2}{5}$,,
,,	40	,,	$188\frac{1}{2}$,,

(ii) Levers linked as in photograph.

Weight	40	pounds,	150 seconds.
,,	45	,,	157 ,,
,,	50	,,	$160\frac{1}{2}$,,
,,	55	,,	$165\frac{3}{5}$,,
,,	60	,,	$171\frac{1}{2}$,,

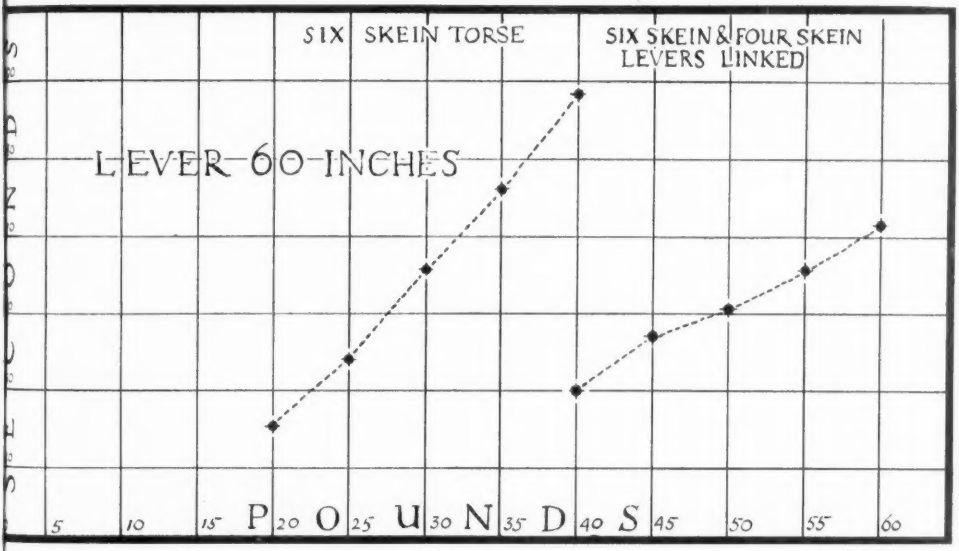


CHART B.

The amplitude of the oscillation also makes a difference. Within the limits of the times recorded, oscillations of 60° take about 7 seconds more per 100 than those of 45° and oscillations of 30° about 3 seconds less than those of 45°.

A point which I would wish to emphasise is this, that I, who am not an athlete, am able to toss 60 pounds of cast iron, up and down, through a height of four or five feet for 100 times running without fatigue; and that the silk springs—the artificial muscles—which enable me to do this weigh only two pounds and half an ounce.

I have concentrated on this aspect of the problem of winged flight because until a muscular or quasi-muscular control of the relative movement of wings and thorax has been obtained there seems to be no possibility of starting the

experiments which should determine the construction and dimensions of the wings.

I hope I may be able to establish a relation between the period of the oscillations above recorded and the period of the wing beats of birds.

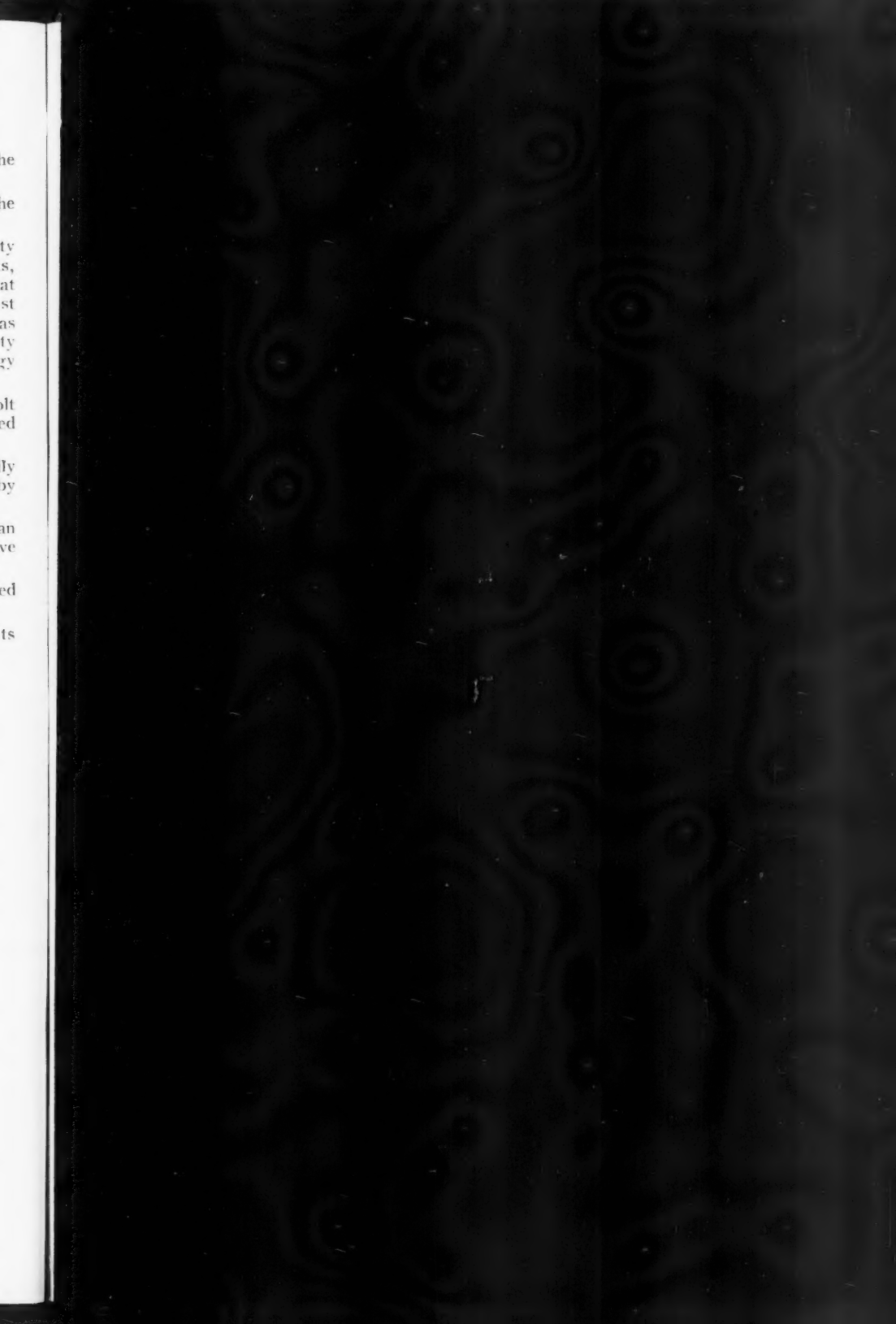
Although birds, when hunting or playing, show a bewildering versatility in their wing movements, yet when they settle down to long distance flights, especially their great migratory flights, they must perforce adopt the wing-beat which allows the greatest economy of nerve impulse, that is to say, they must rely as much as possible on the *postural* activity of muscle, and as little as possible on its *phasic* activity. [Reference: Proceedings of the Royal Society of Medicine, Section of Orthopædics, Presidential Address, "The Physiology of Muscular Action," by A. S. Blundell Bankart, M.Ch., 16th Oct., 1925.]

Those who are familiar with Miss Turner's "Bird Watching on Scolt Head" will recall a very impressive page descriptive of the arrival of the hooded crows.

When birds pass like great armies marching across the sky, one can hardly doubt that to each of them his stride is set by the weight of his body and by the distance out of the centres of air support under his wings.

If this be so, it is likely that the time of the wing-beat is subject to an arithmetic not foreign to that which controls the lever oscillations above recorded.

Later Observations.—Since the completion of the above, I have obtained the following time readings: –

Levers of six-skein and four-skein torses linked; C.G. of weights 75 inches out along the lower lever.

30	lbs.,	100	oscillations	of	45°,	2 min.	$37\frac{3}{5}$ sec.
35	,,	,,	,,			2 ,,	$46\frac{3}{5}$,,
40	,,	,,	,,			2 ,,	$52\frac{2}{5}$,,
45	,,	,,	,,			3 ,,	$0\frac{2}{5}$,,
50	,,	,,	,,			3 ,,	7 ,,